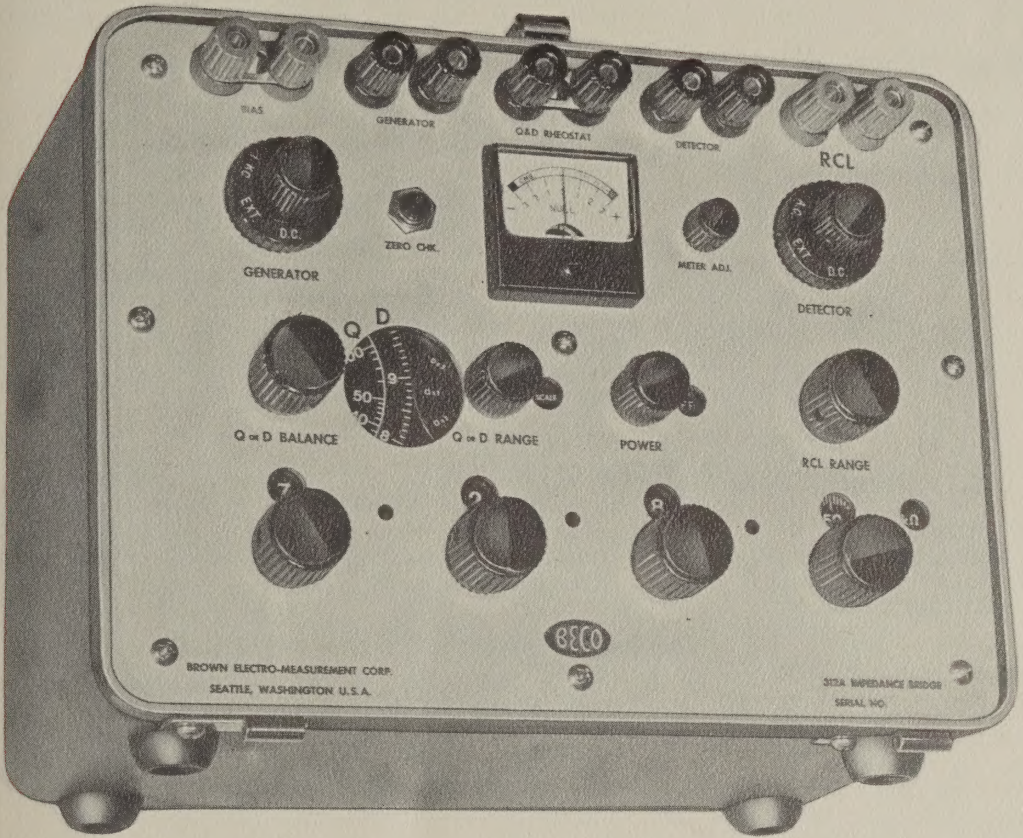
312-A IMPEDANCE BRIDGE



Featuring

- ★ *PRECISION*
- ★ *DIRECT READING*
- ★ *WIDE RANGE*
- ★ *SOLID STATE*
- ★ *SMALL SIZE*
- ★ *PORTABILITY*
- ★ *ELECTRONIC NULL*
- ★ *BATTERY or A.C.*
- ★ *LOW PRICE*

ACCURACY - .05% for resistance

The BECO 312-A Impedance Bridge includes several outstanding features which make it the best universal impedance bridge available. The electronic null detector for D.C. resistance measurement permits .05% accuracy throughout the range of the bridge. The automatic placement of the decimal point in the readout completely eliminates the need for calculation during measurements. The sensitivity of the A.C. null detector is sufficient to permit fast measurements as small as one-tenth of a picofarad or less. BECO manufactures the precision resistors, precision capacitors and precision potentiometers used in the Bridge, and the resistance, capacitance and inductance standards used for calibration of the instrument are all certified against Bureau of Standards measurements. BECO instruments are sold throughout the United States and Canada by leading sales representatives. Our field office near you would be pleased to arrange a demonstration.

BROWN ELECTRO-MEASUREMENT CORP.
827 7th AVENUE, KIRKLAND, WASHINGTON 98033
VA 2-2211

TYPE 312-A IMPEDANCE BRIDGE

RANGES & ACCURACY:

Resistance: 1 milliohm to 12 megohms in 7 ranges.
Accuracy ± (.05% + .001 ohm)

Capacitance: 0.1 picofarad to 1200 microfarads in 7 ranges.
Accuracy ± 0.2%

Inductance: 0.1 microhenry to 1200 henrys in 7 ranges.
Accuracy ± 0.3%

Dissipation Factor (D): .001 to 1.000 at 1 kilocycle.
Accuracy ± (2% + .005)

Storage Factor (Q): 0.1 to 1000 at 1 kilocycle.
Accuracy ± (2% + .005)

BRIDGE STANDARDS:

The wirewound resistors are of low temperature coefficient and are carefully designed for accuracy and stability. The mica capacitance standard is a hermetically sealed unit stabilized and adjusted to better than 0.1% accuracy.

BRIDGE CIRCUITS:

The Wheatstone bridge is used for both D.C. and A.C. resistance measurements. Capacitance is measured in terms of a standard capacitor and precision resistors connected in a four arm bridge network, with provisions for either series or parallel measurements. Both the Maxwell and Hay bridge networks are used for inductance measurements with their respective series or parallel methods.

DETECTOR:

A high gain transistorized amplifier with a frequency selective network is used to drive the panel meter for A.C. measurements. This same amplifier in connection with a photo chopper system is used without the frequency selective network when measuring D.C. resistance. The detector sensitivity is in the order of 10 microvolts.

GENERATOR:

The 1 kilocycle A.C. generator is transistorized and uses a phase shift oscillator followed by a power amplifier and double shielded output transformer to minimize stray capacitance errors when coupling to the bridge networks. A highly insulated D.C. power supply is used to provide voltage for the Wheatstone resistance bridge, and automatic selection of the proper voltage is made for each range of measurement.

SWITCHES:

Silver alloy switches with high grade insulation and dependable ball detents are used throughout the instrument. All critical circuits use paralleled contacts.

CONTROLS:

Three decade switches plus an interpolating slidewire rheostat provide 5-place readout for all ranges of the bridge. The range switch automatically selects the decimal position for the decade reading and also indicates the type of measurement being made. Single knob control is provided for the D and Q balance. Another knob selects either the series or parallel method of measuring capacitance or inductance. Two coaxial controls select the type of generator output and the proper level. Another set of coaxial controls is provided to adjust the detector sensitivity and mode of operation.

TERMINALS:

Five pairs of heavy duty, 5 way, insulated binding posts are provided with a set each for External Detector, External Bias, External Generator, Unknown RCL, and External D or Q.

POWER SUPPLIES:

115 or 230 volts A.C. 50 to 440 cycles, or the bridge may be ordered with an accessory NiCad battery pack. The charging system is an integral part of the power supply and the battery pack may be added at any time. A 6-foot, 3-wire power cord is supplied.

CABINET:

A heavy gauge aluminum cabinet and cover finished in a durable blue vinyl paint is used to house the instrument, and a comfortable carrying handle provides complete portability.

DIMENSIONS:

10-1/2" wide, 7-3/4" high, 8-1/2" deep, with cover.

WEIGHT:

10-3/4 pounds net. 13-1/2 pounds complete with domestic shipping container.

ACCESSORIES:

NiCad battery pack No. 312-2 providing up to 24 hours of continuous service is available for operating the bridge where A.C. power cannot be used.

PRICE:

$470.00, f.o.b. Kirkland, (Seattle) Washington. 312-2 battery pack $97.20, f.o.b. Kirkland, Washington.

REPRESENTED BY:

DATA SHEET B12-965

BROWN ELECTRO-MEASUREMENT CORP.
827 7th AVENUE, KIRKLAND, WASHINGTON 98033
VA 2-2211

TABLE OF CONTENTS

Page

SECTION I - INTRODUCTION

Warranty 1
Specifications 2
General 3

SECTION II - OPERATION

D.C. Resistance Measurements 7
A.C. Resistance Measurements 8
Capacitance Measurements 9
Inductance Measurements 12

SECTION III - SPECIAL MEASUREMENTS

Use of External A.C. Generator 16
External A.C. Null Detector 16
Measurement of A.C. Resistance with Reactance 17
Resonant Frequency of a Tuned Circuit 18
Measurement of an Unknown Impedance or Black Box 19
Measurement of Three Terminal Capacitance 19
Application of D.C. Bias to Capacitors 21
Application of Direct Current to Inductors 22
Control of Voltage Across Unknown Resistor 23

SECTION IV - GENERAL THEORY OF BRIDGE OPERATION 25

Wheatstone Resistance Bridge Circuit 26
Capacitance Bridge Circuit 27
Inductance Bridge Circuits 28
Discussion of Residual Impedances 31

SECTION V - REPAIR AND CALIBRATION PROCEDURE

Trouble Location and Repair 36
Calibration Equipment 39
Calibration Procedure 40
Table 1 43
Table 2 44

SECTION VI - CIRCUIT DIAGRAMS

Fig. 1 Three Terminal Capacitor 45
Fig. 2 Three Terminal Capacitor Connected to Bridge 45
Fig. 3 D.C. Bias to Capacitors 46

TABLE OF CONTENTS - Cont'd.

Page

Fig. 4 D.C. Bias to Inductors 46
Fig. 5 D.C. Resistance Bridge 47
Fig. 6 Capacitance Bridge 47
Fig. 7 Maxwell Inductance Bridge 47
Fig. 8 Hay Inductance Bridge 47
Fig. 9 Resistance Bridge with Residuals 48
Fig.10 Capacitance Bridge with Residuals 48
Fig.11 Maxwell Bridge with Residuals 48
Fig.12 Hay Bridge with Residuals 48
Fig.13 Residual Impedances 49
Fig.14 312-A Switching 50
Fig.15 312-A Impedance Bridge 51
Fig.16 312-A Null Detector 52
Fig.17 312-A Chopper Drive 53
Fig.18 312-A 1 kc Generator 54
Fig.19 312-A Power Supply 55

Repair Parts List 56

SECTION I - INTRODUCTION

WARRANTY

BROWN ELECTRO-MEASUREMENT CORP. warrants each new instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this warranty is limited to repairing or replacing, at our option, any instrument or part thereof except transistors, tubes, batteries, or fuses, which shall within one year after making delivery to the original purchaser be returned to our factory or our factory service representative, with transportation charges prepaid and which upon our examination shall prove to have been thus defective.

BROWN ELECTRO-MEASUREMENT CORP. reserves the right to make changes in design on any instrument at any time without incurring any obligation to make such changes on instruments previously sold.

This warranty is expressed in lieu of all other obligations and liabilities on the part of BROWN ELECTRO-MEASUREMENT CORP., and BROWN ELECTRO-MEASUREMENT CORP. neither assumes or authorizes any other person to assume any other liability in connection with the sale of BECO instruments.

SPECIFICATIONS

RANGES & ACCURACY

The accuracy of the bridge under normal conditions of operation, temperature, and humidity are given in the table below;

Resistance: 1 milliohm to 12 megohms in 7 ranges.
Accuracy ±(.05% + .001 ohm)

Capacitance: 0.1 picofarad to 1200 microfarads in 7 ranges.
Accuracy ± 0.2%

Inductance: 0.1 microhenry to 1200 henrys in 7 ranges.
Accuracy ± 0.3%

Dissipation Factor (D): .001 to 1,000 at 1 kilocycle.
Accuracy ±(2% + .005)

Storage Factor (Q): 0.1 to 1000 at 1 kilocycle.
Accuracy ±(2% + .005)

BRIDGE STANDARDS

The wirewound resistors are of low temperature coefficient and are carefully designed for accuracy and stability. The mica capacitance standard is a hermetically sealed unit stabilized and adjusted to better than 0.1% accuracy.

GENERAL

The BECO 312-A Impedance Bridge is a portable, self-contained instrument designed for use in electrical and electronic work where the value of resistors, inductors and capacitors must be measured accurately. The bridge is used to make direct measurement of RESISTANCE, CAPACITANCE, INDUCTANCE, DISSIPATION FACTOR "D" of capacitors and the STORAGE FACTOR "Q" of inductors. The Model 312-A Impedance Bridge is a four-arm bridge of special design and is housed in an aluminum case which has a detachable lid and a carrying handle.

All controls are located and identified clearly on the front panel. The panel markings for these controls are as follows:

(1) The GENERATOR switch with a coaxial level control.
(2) The ZERO CHECK push button for checking the zero of the D.C. NULL meter.
(3) The METER ADJUST control for zeroing the NULL meter when the ZERO CHECK button is pushed.
(4) The DETECTOR switch with a coaxial gain control.
(5) The Q or D BALANCE control.
(6) The Q or D RANGE SWITCH.
(7) The POWER switch.
(8) The RCL RANGE switch.
(9) The four controls across the bottom of the panel operating the readout decade. The first three of these readout decade controls are switches, and the fourth, or right-hand control, is an

interpolating rheostat with two decades of resistance.

The GENERATOR control switch selects the internal 1 Kc GENERATOR for A.C. measurements; the next position is EXTERNAL GENERATOR, which is required for making A.C. measurements at other than 1 Kc frequency; the next position is D.C. GENERATOR, which connects the internal D.C. supply for measurement of resistance. The coaxial GENERATOR level control is used to operate the output of the 1 Kc internal generator, and usable only in that position.

The DETECTOR switch has an A.C. position used when making 1000 cycle A.C. measurements with the bridge. The next position is the EXTERNAL DETECTOR position, which is used in connection with a vacuum tube voltmeter or oscilloscope or some such method of detecting signals when the bridge is used at frequencies other than 1 Kc. The next position on this switch is the D.C. DETECTOR position. This connects the NULL meter to the bridge circuit when measuring D.C. resistance with the bridge.

The Q or D BALANCE control is used when measuring inductance or capacitance and in determining the loss factors of those measurements.

The Q or D RANGE switch has multiplier positions for both Q and D. It also has a position for using an EXTERNAL C standard and EXTERNAL Q-D rheostat necessary when measuring at other than 1000 cycles.

The POWER switch has an OFF position, an A.C. POWER position, a BATTERY power position, a CHARGE, and a CHECK position.

The RCL RANGE switch automatically selects and indicates in the window at the right-hand end of the readout decade the method of measurement and also the decimal position in that measurement. It automatically selects ohms, kilohms or megohms on the resistance range; microhenrys, millihenrys and henrys on the inductance range; microfarads, nanofarads and picofarads on the capacitance measuring range.

TERMINALS - Five pairs of heavy-duty, 5-way binding posts are located across the top of the panel. On the left-hand side are the D.C. BIAS binding posts, next are the EXTERNAL GENERATOR terminals; next are the EXTERNAL Q & D RHEOSTAT terminals. Fourth are the EXTERNAL DETECTOR terminals, and at the extreme right-hand side is the pair of terminals for the unknown connections of R, C or L.

The D.C. BIAS terminals are used when it is necessary to apply a polarizing voltage to electrolytic capacitors, or when it is necessary to apply a magnetizing current to an inductor for making incremental inductance measurements. These binding posts are also of use in controlling the internal bridge power supply when making measurements of very low wattage or special types of resistors.

The D.C. BIAS terminals are in series with the internal power supplies, both A.C. and D.C., of the bridge.

The set of terminals used for EXTERNAL GENERATOR connections are used only when it is necessary to make measurements on inductors or capacitors at frequencies other than 1000 cycles. These terminals are used to connect to an audio oscillator or A.C. generator of similar type. Any connection to these terminals must be made through a shielded bridge coupling transformer in order to prevent errors. When making measurements of dissipation factor or "Q" at frequencies other than 1 Kc it is necessary to use an external variable resistor.

The EXTERNAL Q & D RHEOSTAT terminals are used to connect to this variable resistor.

The EXTERNAL DETECTOR terminals are used to connect to a suitable detector for use at frequencies other than 1 Kc when making special measurements. Any suitable A.C. detector, such as an oscilloscope, a vacuum tube voltmeter or A.C. millivoltmeter may be used to connect to these detector terminals.

The UNKNOWN RCL binding posts are used to connect to any resistor, capacitor or inductor within the range of measurement of the bridge.

D.C. RESISTANCE MEASUREMENTS

(1) Connect the power cord to 115 volt, 50 to 440 cycle A.C. source. Note: See Fig. 18 for 230 volt operation.

(2) Connect the unknown resistor to the binding posts marked UNKNOWN RCL.

(3) Rotate the left-hand dial in the bottom row to position 3 and set the other dials in that row to zero.

(4) Turn the POWER SWITCH to the A.C. position.

(5) Push the ZERO CHK. button and rotate the METER ADJ. knob until the NULL meter reads exactly zero. Release the button.

(6) Rotate the RCL RANGE switch until the NULL meter moves across zero. Note: The resistance symbols must appear in the window when this dial is rotated and also there are three unmarked positions on this switch which could give false readings. A negative reading on the NULL meter indicates that the bridge decade reading is too low; a positive reading on the NULL meter indicates that the bridge decade reading is too high.

(7) When the NULL meter reads negative, increase the value of the decade readout by progressively from left to right rotating the dials to a higher number. When the NULL meter crosses zero from negative to

positive as the decade dials are rotated, the reading on that particular dial must be decreased by one position. Then go on to the next dial, and in turn adjust it until the meter again crosses zero and that dial then must be decreased by one position also. Go on to the third dial, repeating this, and repeat for each successive decade until the NULL meter reads zero. The bridge is then balanced for the unknown resistance, and the numbers above each dial indicate the proper reading. At the right-hand end of this row of numbers will be the proper term under which the readout is indicated; for example, if the NULL meter balances at zero with the decade set at 1.0931 k ohms, the reading would be 1,093.1 ohms; or, if the bridge balances on the lowest range on a reading of 0.0075 ohms, the resistance of the unknown would be 7½ milliohms.

A.C. RESISTANCE MEASUREMENTS

(1) Rotate the GENERATOR switch to 1 Kc and the DETECTOR switch to A.C.

(2) Connect the unknown resistor to the RCL binding posts.

(3) Set the left-hand readout dial to 3 and the rest of the readout dials to zero.

(4) Turn the GENERATOR level to maximum and adjust the DETECTOR gain control until the NULL meter reads approximately + 2.

(5) Rotate the RCL RANGE switch over the resistance range until the meter reads closest to zero. Note: (The meter will not move across zero as it does for D.C. resistance measurements. In A.C. resistance measurements, or for any A.C. measurement with the bridge, the NULL meter reads zero or close to zero for the best null. It is not phase sensitive as it is in the D.C. resistance type measurements.) As the reading of the NULL meter approaches zero, increase the DETECTOR gain and proceed to balance the bridge for the best null. If it is impossible to get a good null, then the resistance under measurement will be found to be reactive. See the section of this Instruction Manual under "Special Measurements" for measurement of resistance with reactance.

CAPACITANCE MEASUREMENTS

(1) Connect the unknown capacitor to the RCL terminals.

(2) Rotate the POWER switch to the A.C. position.

(3) Rotate the GENERATOR switch to A.C. position and turn the GENERATOR Level control about ⅓ to ½ way, clockwise.

(4) Turn the DETECTOR switch to the 1 K position and rotate the DETECTOR gain clockwise, keeping the meter reading between 1 and 2 on the plus side of the scale.

(5) Set the Q or D RANGE switch to position D x .01 and rotate the Q or D BALANCE dial to position 1 on the scale.

(6) Set the left-hand switch in the decade row of switches to position 3, and all other dials in that row at zero.

(7) Adjust first the RCL RANGE switch, then the left-hand decade switch, then the Q or D BALANCE controls for the minimum reading on the NULL meter. In general, proceed as in making A.C. resistance measurements. If more or less sensitivity of balance is needed, adjust the GENERATOR level control and/or the DETECTOR gain control. Then proceed to obtain the best null balance.

The best null balance will be found when the meter reads closest to zero. It may be necessary, in order to get the best null balance, to set the Q or D RANGE switch to position D x .1. If it is impossible to obtain a good null when the D dial is rotated when the Q or D RANGE switch is in either position, very possibly the capacitor is shorted. An open capacitor would be indicated as a very low value of capacitance, and very likely the dissipation factor would also be low.

At times it is necessary to measure a capacitor with a dissipation factor lower than the range of measurement of the bridge. Such units may be easily measured by including a low non-inductive resistor in series or a high value non-inductive resistor in parallel with the unit under measurement. The proper value of the resistor may be determined by the formula:

$$D = R\omega C$$

where R is the value of the resistor, ω is $2\pi f$ and C is the capacitance of the unit under test.

It will be noted that as the RCL RANGE switch is rotated, the decimal position will change automatically in the decade readout. When the bridge is balanced, the reading will be in picofarads, nanofarads, or microfarads, depending on the position of the RCL RANGE switch.

Note: One picofarad equals one mico-microfarad; one nanofarad equals 1,000 micro-microfarads.

When measuring electrolytic capacitors, first read the section under "Special Measurements".

As balance is approached, the GENERATOR level and A.C. DETECTOR gain controls should be readjusted as desired for better balance indication. Note: The residual capacitance of the bridge must be subtracted from any low capacitance measurements. Residual capacitance is obtained by balancing the bridge as above with the capacitor removed from the UNKNOWN RCL binding posts and the binding posts screwed down. The residual capacitance of the bridge will be less than 1 picofarad.

When making extremely low capacitance measurements, or when making measurements of capacitance at some distance from the bridge, see the section in the Manual under "Special Measurements".

INDUCTANCE MEASUREMENTS

Note: To facilitate inductance measurements and to avoid making possible errors, first read the Paragraph entitled "General Theory of Bridge Operation".

(1) Connect the unknown inductor to the UNKNOWN RCL terminals.

(2) Rotate the POWER switch to the A.C. position.

(3) Rotate the GENERATOR switch to the 1 kc position, and turn the GENERATOR level control about ⅓ of the way, clockwise.

(4) Turn the detector switch to the A.C. position and rotate the detector gain clockwise, keeping the meter reading below 2 on the plus side of the scale.

(5) Set the Q or D RANGE dial to position Q x 1 as read on the D scale. The Q or D BALANCE dial should be set to about 1 on the D scale (this setting applies to inductors with a Q of less than 10) for initial balance. If the Q is greater than 10, set the Q or D RANGE dial to Q x 1 on the Q scale.

(6) Set the left-hand switch in the decade row of switches to position 3, with all the other dials in that row at zero.

(7) Adjust first the RCL RANGE switch, then adjust the left-hand decade switch, then the Q or D BALANCE control for the minimum reading on the NULL meter. In general, proceed as for measuring

A.C. resistance or capacitance. If more or less sensitivity of balance is needed, adjust the GENERATOR level control and/or the DETECTOR gain control, then proceed to obtain the best null balance. The best null will be found when the meter reads closest to zero.

(8) When measuring capacitors or inductors it will be noted that the Q or D dial adjustment and the readout adjustment will inter-act if the usual procedure of adjusting first one control, then the other, is followed. This condition is known as "sliding balance" and is common to both the Hay and Maxwell impedance bridges. When Q is high there is no sliding balance because vectorally the effects of L and Q are perpendicular to each other and thus the ability to get a null is greatly improved. The best procedure to follow in order to permit rapid and accurate low Q measurements is to set the Q dial to its maximum position, then adjust the L readout dial so that the detector reads a minimum. Then alternately set the Q dial for a minimum on the detector. Then in turn move L a small amount, and reset for a minimum, then reset Q for a minimum and observe whether this new reading is better or worse than the previous one. If it is better, move the L readout another small amount in the in the same direction. If it is worse, try the

other direction. By continuing to move the L readout in small steps in one direction only while setting the Q dial for a minimum reading on the detector a point will be reached where the detector signal reaches a true null and moving the L readout dials will then make the condition worse. The true null reading when this practice is followed will permit rapid and accurate measurements of very low Q inductance; however, remember that when Q and L are zero the generator of the bridge is shorted out and no reading on the NULL meter is observed.

The effective inductance of certain coils will change with the excitation voltage; therefore, it is desirable to use the minimum GENERATOR level compatible with the required accuracy of measurement. On some measurements the Q or D BALANCE control will be extremely sharp in adjustment, and it is necessary to adjust slowly in order to get the best null.

An inductance of high value will occasionally have sufficient shunt capacitance to become resonant near the 1 kc operating frequency of the bridge. This condition, of course, prevents accurate measurement of the inductance. Therefore, it is necessary to use an external A.C. generator and detector operating at a frequency of 100 cycles in order to accurately measure such inductance.

The bridge measures either series or parallel inductance, depending on the Q of the inductor under measurement. If the inductor under test is open, it will be impossible to obtain a null balance. An open inductor will usually measure as the equivalent of a low value capacitor. An inductor with shorted turns will usually have associated with it a very low Q.

When checking the bridge against Standards, it is always desirable to know the type of measurement against which the standard has been certified, as there is a 1% difference between series and parallel inductance measurements. For more information, see SECTION IV - Inductance Bridge Circuits.

SECTION III - SPECIAL MEASUREMENTS

USE OF EXTERNAL A.C. GENERATOR

An external A.C. generator or audio oscillator may be connected to the bridge for making A.C. resistance, capacitance and inductance measurements at frequencies other than 1 kc. The maximum power from the generator into the bridge must not exceed 1 watt. To use an external A.C. generator with the bridge, proceed as follows:

(1) Connect the generator to the EXTERNAL GENERATOR binding posts through a suitably shielded bridge transformer to avoid errors.

(2) Connect the shield of the transformer to the generator ground.

(3) Rotate the bridge GENERATOR switch to EXTERNAL. Note: High capacitance to ground will appear across the A.C. generator power transformer and then back through the bridge power transformer through the A.C. power line. If a shielded bridge transformer is not used, errors will result.

EXTERNAL A.C. NULL DETECTOR

When using the bridge at any frequency other than 1 kc it is necessary to connect an external A.C. null detector to the EXTERNAL DETECTOR binding posts. The DETECTOR switch is rotated to EXTERNAL. The EXTERNAL A.C. NULL detector must have a sensitivity in the order of 10 microvolts in order to be most effective.

MEASUREMENT OF A.C. RESISTANCE WITH REACTANCE

To obtain a sharp null when measuring resistors having appreciable reactance, an external calibrated variable capacitor may be used with the bridge as follows:

(1) Connect the resistor to the UNKNOWN RCL binding posts.

(2) Set up the bridge for use with an external A.C. generator and null detector.

(3) Connect the calibrated capacitor between the EXTERNAL DETECTOR G binding post and the EXTERNAL GENERATOR binding post next to the D.C. BIAS terminals.

(4) Balance the bridge in the usual manner for A.C. resistance measurements. When null is approached, vary the external capacitor to increase the null sensitivity. If a completely sharp null is obtained, the resistor is inductive and the Q may be computed from the equation:

$$Q = 2\pi fRC$$

Where f is the frequency of the external generator, R is 1 kilohm, and C is the capacitance of the external variable capacitor at balance, indicated in microfarads.

(5) If a sharp null cannot be obtained, the resistor may be capacitive, in which case connect the external variable capacitor between the left-hand UNKNOWN RCL binding post and the left-hand EXTERNAL GENERATOR binding post.

(6) Balance the bridge in the usual manner. If the resistor has some capacitive reactance, the null sensitivity will be increased by varying the external capacitor. The Q or D of the resistor may be calculated as follows:

$$Q = 2 \pi fRC$$

$$D = \frac{1}{Q} = \frac{1}{2 \pi fRC}$$

Where f is the frequency of the EXTERNAL GENERATOR in kilocycles, R is the value in kilohms of the ratio arm resistor in use for the particular range selected. C is the capacitance of the external variable capacitor at balance in microfarads. See Table 1 for the value of the ratio arm resistor selected.

RESONANT FREQUENCY OF A TUNED CIRCUIT

The resonant frequency of a series or parallel LC combination may be determined using the bridge and an external A.C. generator and detector up to a frequency of approximately 20 kc's. Proceed as follows:

(1) Connect the LC combination to the UNKNOWN RCL binding post.

(2) Connect a variable frequency A.C. generator to the bridge through a suitably shielded coupling transformer.

(3) Turn the bridge generator switch to EXTERNAL.

(4) Connect a suitable null detector to the EXTERNAL DETECTOR binding posts and rotate the DETECTOR switch to EXTERNAL.

(5) Obtain a null by varying the generator frequency, the RCL RANGE knob in the resistance mode, and the readout dials of the bridge. The generator frequency when a null occurs is the resonant frequency of the LC combination.

MEASUREMENT OF AN UNKNOWN IMPEDANCE OR BLACK BOX

(1) Connect the unknown to the RCL binding posts, and measure for A.C. resistance.

(2) If a balance is obtained, measure again for D.C. resistance. If a balance is obtained at approximately the same reading as for A.C. resistance, the unknown impedance is a resistor. If a much lower D.C. resistance is obtained than the A.C. resistance, the unknown is an inductor. If no D.C. resistance is obtained, the unknown is a capacitor.

MEASUREMENT OF 3-TERMINAL CAPACITANCE

(1) Occasionally it is necessary to measure a capacitance that is shunted by stray capacitances, such as the 3-terminal capacitor in Fig. 1. C_X is the direct capacitance to be measured, and C_A and C_B are stray capacitances whose effects are to be eliminated from the measurement. To measure the direct capacitance, connect the third terminal of the capacitor to the G binding post of the EXTERNAL DETECTOR terminals. Fig. 2 shows the resulting bridge connection. C_A shunts the

detector circuit, causing a significant reduction of detector sensitivity only if the capacitance is very large. C_B shunts the D rheostat and the standard capacitor, C_S. If C_B is small, its effect can be neglected and the ratio arm reading may be used directly. A value of 50 picofarads across the standard C_S will cause the bridge to read about .05% low.

(2) If C_B is too large to neglect, the bridge reading may be multiplied by a correction factor to obtain the actual value of C_X. To calculate C_X use the formula:

$$C_X = R\left[1 + \frac{C_B}{100{,}000 \text{ pf}}\right]$$

Where C_X is the actual capacitance, R is the range arm reading in ohms. See Table 1. C_B is the estimated shunt capacitance in picofarads. 100,000 pf is the size of the standard capacitor in the bridge.

(3) If C_B cannot be estimated, C_X may still be calculated by taking one additional reading with a capacitor of known value that is large, or larger than C_X, placed in parallel with C_X. The capacitor should not add significantly to the C_B. Use the formula:

$$C_X = R_1\left[\frac{C_Y}{R_2 - R_1}\right]$$

Where C_X is the actual capacitance, R_1 is the range arm, C_Y is the value of the capacitor placed in parallel with C_X, R_2 is the range arm reading with

C_X and C_Y in parallel.

(4) A 3-terminal capacitance may be easily devised to make measurements of capacitance at considerable distance from the bridge. This is accomplished by using low capacitance shielded leads and connecting the shields to the ground binding post of the EXTERNAL DETECTOR. If necessary, the foregoing formulas may be used if the capacity of the leads is considerable.

APPLICATION OF D.C. BIAS TO CAPACITORS

Certain types of capacitors require a polarizing voltage when being measured. As an example, tantalum and electrolytic capacitors may give erroneous readings on the bridge, or may even be damaged by the reverse polarity half cycle of the bridge generator frequency. This precaution need not be observed if the A.C. voltage from the generator is kept below about ½ volt across the capacitor under test. However, it is usually advisable to apply a D.C. voltage comparable to the rating of the device under test when measuring any polarized capacitor. Up to 600 volts of D.C. bias may be applied to the unknown capacitor. See Fig. 3 for connections.

WARNING: Charged capacitors form a shock hazard, and care should be taken to insure personal safety during measurement.

The external D.C. supply used during these measurements should also be carefully handled.

One side of the bridge detector is grounded; therefore, it is impossible to use a D.C. power supply or D.C. source that has one side grounded. A grounded supply would short out one arm of the bridge.

The best type of power supply to use for measurements such as described would be a well insulated battery pack. It is necessary to limit the power that may be drawn from the external D.C. bias supply to ½ watt in order to protect the bridge components in case the unknown capacitor is short circuited.

APPLICATION OF DIRECT CURRENT TO INDUCTORS

Direct current may be applied to inductors so that incremental inductance measurements may be made. The D.C. power supply is connected to the BIAS terminals of the bridge in accordance with Fig. 4. The maximum current usable in this measurement is limited to that given in Table 2. A grounded D.C. source cannot be used because one of the bridge detector terminals is grounded. A well insulated battery is the recommended D.C. source, as most line operated D.C. power supplies have high capacity to the A.C. power line. This high capacity could fall across one of the bridge arms, thus causing large errors in measurement.

CAUTION: The external D.C. supply used during these measurements should be carefully handled so as to insure personal safety and prevent damage to the bridge or equipment under test.

APPLICATION OF D.C. BIAS WHEN MEASURING A.C. RESISTANCE

Various types of non linear resistive devices, such as diodes, thermistors, and varistors are best measured with a D.C. bias voltage applied in order to determine the small A.C. signal resistance. For thermally sensitive units the A.C. resistance of these is essentially equal to the D.C. resistance as long as the time constant is much greater than the period of the A.C. signal. For voltage sensitive elements such as diodes and varistors the A.C. resistance is essentially the slow of the D.C. voltage current curve. See Fig. 5 for the proper connections of the bias voltage in order to make these measurements.

The current to the bridge must be limited to that given in Table 2 in order to prevent damage to the bridge arms. The current in the device under test is equal to the current supplied through the D.C. BIAS terminals multiplied by

$$\frac{R_B}{R_A + R_B}$$

The value of R_A and R_B for any range is available in Table 1.

A well insulated battery should be used as the source for the D.C. bias.

WARNING: Care must be used in making such measurements so as not to damage the device under test or the bridge.

CONTROL OF VOLTAGE ACROSS UNKNOWN RESISTOR

Quite often it is desirable to measure a resistor and minimize the voltage across this unknown resistor. With the conventional impedance bridge or wheatstone bridge this is quite difficult in that there is no method of varying the voltage across the bridge arms. However, with the 312-A Impedance Bridge all that is necessary is to connect a suitable decade box across the BIAS terminals of the bridge after disconnecting the shorting link. The BIAS terminals are in series with the bridge power supply; therefore, it is possible to control the current through the bridge arms, and in this manner effect a voltage across the device under measurement.

MEASUREMENT OF DISSIPATION FACTOR (D) AND STORAGE FACTOR (Q) AT FREQUENCIES OTHER THAN 1 kc

The resistance required for other frequencies or dissipation factor ranges may be derived from the formula: $R(\text{k ohm}) = \frac{1.592D}{f(\text{kc})}$. For calculating the proper resistance necessary for determining storage factor at other frequencies, use the formula: $R(\text{k ohms}) = \frac{1.592}{Qf(\text{kc})}$. The Q or D RANGE dial must be rotated to position Ext. DQ and the shorting link between the External Q or D RHEOSTAT binding posts disconnected to permit connection of the external variable resistor.

EXTERNAL CAPACITANCE STANDARD

Rotating the Q or D RANGE switch to position Ext. C permits the connection of an external capacitance standard to the External Q or D RHEOSTAT binding posts. The necessary Q and D BALANCE rheostat must be connected with this external standard capacitor to provide the proper readings.

SECTION IV

GENERAL THEORY OF BRIDGE OPERATION

A bridge is an arrangement of impedances for the measurement of various electrical properties. The basic form, Fig. 5, consists of four resistance arms: R_X, N, A, and B. The ratio of the A and B resistances is adjustable so that the variable resistor, N, serves as a standard in measuring a wide range of resistor values. All four resistances are connected in series parallel to a supply or battery between the junctions of the R_X and N and the A and B arms. When the voltage drop across arm R_X equals the drop across arm N, and the voltage drop across arm A equals the drop across arm B no current flows through the detector, and the bridge is considered to be balanced.

This condition of balance may be expressed by the formula:

$$\frac{R_X}{A} = \frac{N}{B}$$

By substituting capacitor-inductor or capacitor-resistor combinations in series or in parallel for the bridge resistors, the bridge may be used to measure A.C. resistance, capacitance, inductance, dissipation factor and storage factor. Selection of these various bridge combinations for the 312-A Impedance Bridge is made by turning the RCL RANGE knob. The ratio arms of the bridge are also controlled by this knob, and are automatically selected as the mode of operation or the position of the decimal point is changed. When making A.C. measurements of inductance or capacitance, it is necessary to adjust the RCL RANGE, the Q or D BALANCE and the readout dials in order to obtain a null. The bridge is considered balanced when the lowest null reading is obtained.

DESCRIPTION OF THE BRIDGE CIRCUITS USED

WHEATSTONE RESISTANCE BRIDGE CIRCUIT

The Wheatstone Resistance Bridge is used to make A.C. and D.C. resistance measurements. The circuit is arranged as shown in Fig. 5. This circuit arrangement is obtained by setting the RCL RANGE knob to any ohm, kilohm, or megohm position. The basic equation of balance for the Wheatstone Resistance Bridge is:

$$R_X = \frac{R_N\ R_A}{R_B}$$

R_A, R_N and R_B are calibrated to make the bridge direct reading. When the bridge is used for making A.C. resistance measurements, errors are introduced by the small residual capacitances and inductances associated with the bridge arms and the unknown. Generally, the residual inductance effects are negligible, but the residual capacitance effects may introduce errors in high impedance measurements.

Fig. 9 shows the Wheatstone Resistance Bridge with residual capacitances associated with the bridge arms. The complete balance equation for this A.C. resistance bridge is:

$$R_X = \frac{R_A\ R_N}{R_B} \left[\frac{1 + Q_B\ (Q_N + Q_A) - Q_A\ Q_N}{(1 + Q_A^{\ 2})\ (1 + Q_N^{\ 2})} \right]$$

Where the terms within the bracket represent a correction factor to be applied to the reading to obtain the true value of the unknown resistance.

This type of measurement will have an associated "Q". The Storage Factor balance equation is:

$$Q_X = \frac{Q_B (1 - Q_A Q_N) - Q_A - Q_N}{1 + Q_B (Q_N + Q_A) - Q_A Q_N}$$

The value of R_A is to be determined from the setting of the RCL RANGE dial and the decimal position. The value of R_N is the reading of the readout dial multiplied by 1000 ohms. The value of C_A is approximately 7 picofarads. The value of C_N is approximately 20 picofarads when the internal generator is used.

Q_B may be determined as outlined under "Measurement of A.C. Resistance with Reactance".

CAPACITANCE BRIDGE CIRCUIT

The capacitance bridge is used for measuring the capacitance and dissipation factor of capacitors. The circuit is arranged as shown in Fig. 6.

This circuit arrangement is obtained by setting the RCL RANGE dial to any position indicating microfarads, nanofarads, or picofarads. The Q or D RANGE switch should also be set to D x .01 or D x .1. The basic equation of balance of the capacitance bridge is:

$$C_X = C_B \frac{R_N}{R_A} \quad \text{and} \quad D_X = R_B$$

Where R_N, R_A, C_B and R_B are calibrated to make the bridge direct reading. However, errors are introduced by the small residual inductances and capacitances associated with the bridge arms. Generally, the residual inductance effects are negligible, but the residual capacitance effects may introduce some errors when the capacitance being measured is small.

Fig. 10 shows the residual capacitances associated with the bridge. The complete balance equation for the bridge circuit is:

$$C_X = C_B \frac{R_N}{R_A} \left[\frac{1 + Q_A{}^2}{1 + D_B (Q_A - Q_N) + Q_A Q_N} \right]$$

Where the terms within the bracket represent a correction factor to be applied to the readings to obtain the true value for C unknown.

The dissipation factor balance equation is:

$$D_X = \frac{D_B + Q_N - Q_A (1 - Q_N D_B)}{1 + D_B (Q_A - Q_N) + Q_A Q_N}$$

In both equations

$$Q_N = R_N \omega C_N, \quad Q_A = R_A \omega C_A$$

C_A is approximately 7 picofarads and C_N is approximately 20 picofarads.

INDUCTANCE BRIDGE CIRCUITS

The Maxwell Inductance Bridge is used for measuring inductances with storage factors below 10. The circuit is arranged as shown in Fig. 7.

This circuit arrangement is obtained by setting the RCL RANGE control to any henry, millihenry or microhenry readout, and turning the Q or D RANGE knob to Q x 1, D scale. The balance equation for the Maxwell Inductance Bridge is:

$$L_X = R_A R_N C_B \quad \text{and} \quad Q_X = Q_B$$

Where R_A, R_N, C_B and Q_B are calibrated to make the bridge direct reading. However, errors are introduced by the small residual inductances and capacitances associated with the bridge arms.

Generally, the residual inductance effects are negligible, but the residual capacitance effects may introduce errors when the inductance being measured is above 10 henrys.

Fig. 11 shows the Maxwell Inductance Bridge with the residual capacitances associated with the various bridge arms. The complete balance equation for series inductance measured by this bridge is:

$$L_X = R_A R_N C_B \left[\frac{1 - Q_A/Q_B - Q_N/Q_B - Q_A Q_N}{(1 + Q_A^2)(1 + Q_N^2)} \right]$$

Where the terms within the bracket represent the correction factor to be applied to the reading to obtain the true value of the unknown inductance.

The storage factor balance equation is:

$$Q_X = \frac{Q_B (1 - Q_A Q_N) - Q_A - Q_N}{1 + Q_B (Q_A + Q_N) - Q_A Q_N}$$

In both equations Q_A equals $R_A \omega C_A$, $Q_N = R_N \omega C_N$, where C_A is approximately 7 picofarads, and C_N is approximately 20 picofarads.

The Hay Inductance Bridge is used for measuring inductances with storage factors between 10 and 1000.

The circuit arrangement is shown in Fig. 8, and is obtained by setting the RCL RANGE control for any henry, millihenry, or microhenry range, and the Q or D RANGE control to Q x 1, Q scale. The basic equation of balance for the Hay Inductance Bridge is:

$$L_X = R_A R_N C_B$$

$$Q_X = Q_B$$

Where R_A, R_N, C_B and Q_B are calibrated to make the bridge direct reading.

However, errors are introduced by the small residual inductances and capacitances associated with the bridge arms. Generally, the residual inductances are negligible, but the residual capacitance effects may introduce errors when the inductor being measured is above 10 henrys.

Fig. 12 shows the Hay Inductance Bridge with the residual capacitances associated with the various bridge arms. The complete balance equation for parallel inductance measured by this bridge is:

$$L_X = R_A R_N C_B \left[\frac{1 - Q_A/Q_B - Q_N/Q_B - Q_A Q_N}{(1 + Q_A^2)(1 + Q_N^2)} \right]$$

Where the terms bracketed, in order of their importance, represent correction factors to be applied to the reading to obtain the true value of L unknown.

The storage factor balance equation is:

$$Q_X = \frac{Q_B (1 - Q_A Q_N) - Q_A Q_N}{1 + Q_B (Q_A + Q_N) - Q_A Q_N}$$

In both equations

$$Q_A = R_A \omega C_A, \quad Q_N = R_N \omega C_N$$

Where C_A is approximately 7 picofarads and C_N is approximately 20 picofarads.

The equation relating the Maxwell and the Hay Bridge methods of measurement, or the series inductance L_S as compared to the parallel inductance L_P measurements is:

$$L_P = \frac{1 + Q^2}{Q^2} L_S$$

DISCUSSION OF RESIDUAL IMPEDANCES

GENERAL - The causes of residual inductance, capacitance, and resistance must be considered in any bridge circuit because no impedance element, however, carefully constructed, is free from residual impedances. Inductors have associated resistance and shunt capacitance, resistors have series inductance and shunt capacitance, and even air capacitors have series resistive and inductive residual impedances.

Fig. 9, 10, 11 and 12 show the most significant residuals in the Wheatstone Resistance Bridge, the capacitance bridge, and the Maxwell and Hay Inductance Bridges. The measured residuals and complete balance equations are given in the preceding paragraph. From these, should the precision of measurement demand, the percentage of error due to residuals can be recognized, computed, and corrections made.

RESIDUAL IMPEDANCES IN RESISTORS - Every resistor contains residual components of capacitance and inductance. The magnitude of these components is determined by the type and construction of the resistor. Residuals can be balanced at only one frequency: at higher or lower frequencies the capacitance or inductance error predominates. Capacitance and inductance effects are undesirable, especially in precision resistors, and many methods of construction are employed to reduce residual impedances.

Fig. 13A shows how residuals are usually associated with a resistor.

(1) Capacitance exists between adjacent turns of wire in a resistor. A resistor containing many turns of fine wire has considerable capacitance between turns. When direct current is applied, the residual capacitance (C_P) does not affect the true ohmic value (R) of the resistor except by loss through insulation. If an alternating current is applied, however, energy flows through the parallel path offered by the capacitance between turns, and the impedance (Z_S) of the resistor is changed.

(2) Inductance (L_S) is an equally important residual found in resistors. The amount of inductance is influenced by the type of construction of the resistor. Residual inductance is caused primarily by winding methods that do not cancel magnetic fields set up by the loops or coils of wire in the resistor. The effective impedance (Z_S) of the resistor is increased with an increase in inductance or frequency.

(3) The 312-A Impedance bridge does not contain direct methods for measuring residual impedances in an unknown resistor. Such measurements may be made as outlined under "Measurements of A.C. Resistance with Reactance".

RESIDUAL IMPEDANCES IN CAPACITORS - Residual impedance components of inductance and resistance are associated with all capacitors.

(1) Inductance is introduced principally by the leads, frame, plate construction, and method of winding or stacking the plates. Inductance losses, which are usually low and apparent only at high frequencies, will not be discussed here.

(2) The resistance component is made up primarily of leakage or losses in the capacitor dielectric. Included in this loss is dielectric absorption, which is caused by imperfect insulation. Dielectric absorption is the inability of a capacitor to release its total charge when subjected to cyclic charge and discharge, as in an A.C. circuit. Ohmic resistance of leads and plates also contributes some loss.

(3) All the residual impedances together contribute to the dissipation factor (D) of a capacitor. A capacitor with residual impedances may be represented as a perfect capacitor (C_S) (no losses) in series with a resistance (R_S) (Fig. 13D). (D) is the ratio of series resistance to series reactance (R_S/X_S) and varies with the losses. In Fig. 13E (D) is the cotangent of the angle θ (angular phase displacement). Sometimes capacitor losses are called pf (power factor),

which is the cosine of the angle θ, and differs from (D) by less than 1 percent for dissipation factors less than 0.1.

(4) When the impedance bridge is set up to measure capacitance, the unknown is compared with standard capacitor C36 in the bridge (fig. 14). Capacitor C36 is connected in series with variable resistor R85 or R86 (depending on the setting of the Q or D RANGE switch). The small resistance losses in capacitor C36 are considered when resistor R85 or R86 is calibrated. As the bridge is balanced, the resistance of R85 or R86 is increased or decreased by rotating the Q-D dial until, at balance, its resistance is equal to the equivalent loss resistance of the unknown capacitor. Thus, the reading of the Q-D dial is a direct indication of resistance losses in the unknown capacitor under test. The Q-D dial is calibrated in D values from 0.001 to 1.0. The higher the Q-D dial reading, the greater the losses in the unknown capacitor.

RESIDUAL IMPEDANCES IN INDUCTORS - The first-order residual impedances found in an inductor are series resistance and parallel capacitance (Fig. 13C).

(1) Resistance in an air core inductor consists principally of series resistance of the wire and parallel losses in insulation of the wire or sealing compound. In an iron core inductor further losses are introduced by eddy current and hysteresis losses in the core iron. Residual capacitance is made up primarily by the capacitance between adjacent turns in the winding, and capacitance between the winding and the core.

(2) In an inductor, the effect of residual impedances may be represented as a resistor (R_S) in series with an inductor (L_S), and a capacitor (C_P) in parallel with the R_S and L_S combination (Fig. 13C).

(3) The combined residual losses determine the storage factor (Q) of the inductor; (Q) is the ratio of the series reactance to series resistance (X_S/R_S). In Fig. 13B the (Q) of an inductor is shown as the tangent of the angle. (Tangent θ = side opposite/side adjacent = reactance (X_S) / resistance (R_S), and is a direct indication of the quality of the inductor. The higher the (Q), the better the quality of the unknown inductor.

(4) When the impedance bridge is set up to measure inductance, the inductor under test is compared to a standard capacitor C35 (Fig. 14). This comparison is possible in a bridge circuit because unlike reactances may be compared if their phase differences are considered and the bridge arms are arranged accordingly. Figure 14 shows how this is done. Resistor R85 (Fig. 14) is connected in parallel (depending on the setting of the Q-D RANGE switch) with capacitor C35 in the bridge circuit. When the bridge is balanced, resistor R84 or R85 is adjusted so that it is equivalent to the loss resistance of the unknown inductor under test. The Q-D dial, which controls resistors R84 and R85, reads Q values directly, and is calibrated from 0.01 to 1,000 to cover the required ranges.

TROUBLE LOCATION AND REPAIR

SYMPTOM	PROBABLE CAUSE	PROCEDURE
Bridge inoperative for D.C. measurements.	No power to bridge.	Check A.C. power source and Fuse F1
	Faulty transistors.	Check Transistors Q2 thru Q8
	No voltage on chopper drive lamp N1	Check output of Transformer T1
	No signal thru amplifier	Check P1 and N1
	Open, shorted or defective bridge resistors.	Check Resistors R60 thru R77
	NULL meter.	Check Meter M1
	No voltage to amplifier board or bridge arms.	Check Capacitors C32, C33 and C34 and Zener Diode D8 and Diodes D4 thru D7.
	D.C. Bias Jumper removed.	Replace D.C. Bias Jumper.
	Faulty Decade Rheostat R59	Check for proper resistance and dirt on windings. Remove dirt with cotton swab and alcohol.

TROUBLE LOCATION AND REPAIR

SYMPTOM	PROBABLE CAUSE	PROCEDURE
Bridge inoperative for D.C. measurements.	Faulty switches.	Check all switches for proper contacts and operation.
Bridge inoperative for A.C. resistance measurements.	No A.C. voltage to bridge arms.	Check Transformer T2, Resistor R40, Transistors Q9 and Q10, Capacitors C26, C27, C30 and C31, Diode D1.
	D.C. Bias Jumper removed.	Replace D.C. Bias Jumper.
Bridge inoperative for Inductance and Capacitance measurements.	See symptoms for D.C. and A.C. measurements.	Test as outlined for A.C. and D.C. inoperative symptoms.
	Defective Q or D Rheostat or Standard Capacitor.	Check Standard Capacitor assembly C35-C36. Check Resistors R84, R85 and R86.
	Faulty switches.	Check all switches for proper contacts and operation.
	Q-D Binding Post Jumper removed.	Replace Q-D Jumper.
Line fuse blows instantly when power is turned on.	Defective filter.	Check Capacitors C32, C33 and C34.

TROUBLE LOCATION AND REPAIR

SYMPTOM	PROBABLE CAUSE	PROCEDURE
Line fuse blows instantly when power is turned on.	Defective rectifier	Check Rectifiers D4, D5 and D7. D6
	Defective Zener Diode.	Check Diode D8.
	Defective power transformer.	Check windings for short circuits and check for shorted transformer leads. Replace if necessary.
Unstable or incorrect 1 kc oscillator frequency.	Defective Q9 or Q10.	Replace if necessary.
	Defective C30	Replace if necessary.
	R50 out of adjustment.	Connect 403B A.C. voltmeter to D.C. BIAS terminals with link removed. Rotate GENERATOR switch to 1 kc and GENERATOR level to maximum. Adjust Resistor R50 for meter reading of 4 volts. Check waveform. Connect H.P. Counter to D.C. BIAS terminals and measure frequency. Capacitors C28, C29 and Resistors R44 and R45 control frequency. A defective capacitor C30 will also cause a frequency shift.

CALIBRATION EQUIPMENT

The BECO 312-A Impedance Bridge is calibrated against Standards traceable to the U. S. Bureau of Standards.

The following equipment, or equal, is recommended for use in repair, recalibration or recertification of the Impedance Bridge:

1	Hewlett Packard 403B A.C. Voltmeter
1	Hewlett Packard 5211B Electronic Counter
1	Hewlett Packard 140A Oscilloscope, with
1	Hewlett Packard 1400A Differential Amplifier, and
1	Hewlett Packard 1420A Time Base
1	Leeds & Northrup 4020B Standard Resistor
1	Leeds & Northrup 4025B Standard Resistor
1	Leeds & Northrup 4030B Standard Resistor
1	Leeds & Northrup 4035B Standard Resistor
1	Leeds & Northrup 4040B Standard Resistor
1	Leeds & Northrup 4045B Standard Resistor
1	Leeds & Northrup 4050B Standard Resistor
1	General Radio 1409L Standard Capacitor
1	General Radio 1409T Standard Capacitor
1	General Radio 1482E Standard Inductor
1	General Radio 1482N Standard Inductor
1	BECO Model 308-A Wheatstone Resistance Bridge
1	Simpson Model 260 Multimeter
1	#6 and #8 Allen Head Wrench
1	Screwdriver
1	Phillips Screwdriver
1	#8 Spintite Hex. Nut Driver
	Transistor lead heat sinks
	Small soldering iron

CALIBRATION PROCEDURE

Calibration of the 312-A Impedance Bridge is made on a direct comparison basis against known Standards.

D.C. CALIBRATION

(1) Set up the bridge for D.C. resistance measurements.

(2) Connect a heavy copper strip between the RCL binding posts and measure the D.C. residual resistance of the bridge. Record this measurement.

(3) Connect the 1 ohm Standard to the bridge through short, heavy leads. If the leads are more than a total of 6" in length, or the wire smaller than #10 the lead resistance must be known and allowed for.

(4) Balance the bridge and record the reading after subtracting the residual bridge reading.

(5) Proceed as in above, using the 10 ohm Standard and the 100 ohm Standard resistors.

(6) Measure the remaining Standard resistors: 1 kilohm, 10 kilohms, 100 kilohms and 1 megohm, although it is not necessary to deduct the residual resistance reading for these measurements.

(7) Connect the decade resistor box to the bridge, and with all controls at zero on the decade resistor, measure the residual resistance of the decade resistor. Record this reading.

(8) Proceeding with the lowest value resistance on the decade box, measure each step, 1 through 9, with a corresponding dial on the 312-A bridge. Proceed through all readout dials on the 312-A bridge with this measurement. This will establish the accuracy and continuity of the readout dials. Remember to deduct the residual resistance from all readings below about 1000 ohms, if significant.

CAPACITANCE CALIBRATION

(1) Set the bridge as for measuring capacitance.

(2) Measure the residual capacitance of the bridge and record the reading.

(3) Connect a 1409L Standard capacitor to the bridge with a .1 megohm 1% resistor in parallel. The leads must be as short as possible both to the capacitor and to the resistor. Deduct the residual capacitance from this reading and record. Calculate for the equivalent (D) and compare to the dial reading.

(4) Connect the 1409T Standard capacitor to the bridge and measure as above.

(5) If the readings are out of tolerance, replace trimmer capacitor C36 across Standard capacitor C35 with a trimmer of the proper value.

INDUCTANCE CALIBRATION

(1) Connect the 1482E Standard inductor to the bridge through short, heavy leads. Rotate the Q-D RANGE

dial to Q x 1 on D scale for measurement of series inductance. Balance for L and Q. Record the readings.

(2) Connect the 1482N Standard inductor to the bridge through short, heavy leads. Rotate the Q-D RANGE switch to Q x 1 as read on the Q scale for parallel inductance. Balance the bridge for L and Q measurements.

NOTE: The Standard inductors have been measured as effective parallel inductances; however, the Standards are calibrated in effective series inductance; therefore, the difference in the readings will be approximately 1% between the 1482E and the 1482N. Allowance must be made for this difference for certification purposes.

See SECTION II and SECTION IV for inductance measurements.

ADDENDA TO D.C. RESISTANCE MEASUREMENTS AND D.C. CALIBRATION PROCEDURE

When measuring resistors where chance exists for unusually high A.C. pickup, or when using long leads, or when working in an area of high fields, it will be necessary to shield the leads from stray pickup. Certain levels of stray pickup can cause discrepancies between ranges when measuring D.C. resistance. This is due to the coupling of these stray fields into the electronic null detector of the bridge.

When measuring certain types of resistors with metal enclosures, a great deal of capacitance may exist between the resistor and the enclosure, thus introducing hum pickup into the null detector circuit.

It is important to ground the shield during such measurements.

TABLE I

RATIO RESISTOR VALUES FOR VARIOUS RCL RANGE SWITCH SETTINGS

RCL RANGE DIAL AND DECIMAL POSITION	RATIO RESISTOR ARM 'A"	RATIO RESISTOR ARM "B"
0.0000 ohm	1 ohm	1 K ohm
00.000 ohm	10 ohms	1 K ohm
000.00 ohm	100 ohms	1 K ohm
0.0000 kilohm	1 kilohm	1 K ohm
00.000 kilohm	10 kilohms	1 K ohm
000.00 kilohm	100 kilohms	1 K ohm
0.0000 megohm	1 megohm	1 K ohm
000.00 microhenry	1 ohm	
0.0000 millihenry	10 ohms	
00.000 millihenry	100 ohms	
000.00 millihenry	1 kilohm	
0.0000 henry	10 kilohms	
00.000 henry	100 kilohms	
000.00 henry	1 megohm	
000.00 microfarad	1 ohm	
00.000 microfarad	10 ohms	
0.0000 microfarad	100 ohms	
000.00 nanofarad	1 kilohm	
00.000 nanofarad	10 kilohms	
0.0000 nanofarad	100 kilohms	
000.00 picofarad	1 megohm	

NOTE: Refer also to Table 2 and Figures 5, 6, 7 & 8.

TABLE 2

MAXIMUM CURRENT THROUGH BRIDGE RATIO ARMS

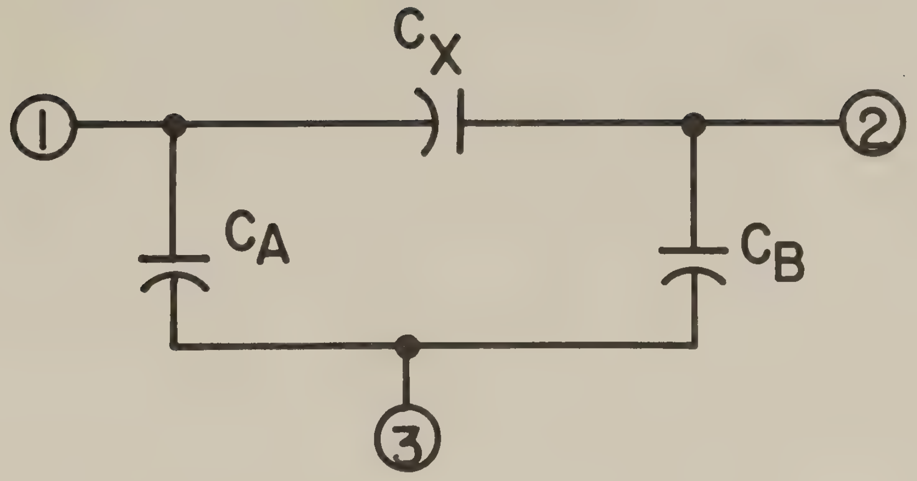
RATIO RESISTOR ARM "A"	RATIO RESISTOR ARM "B"
1 ohm = 710 ma - 0.71 V	1 kilohm = 23 ma - 23 V
10 ohms = 230 ma - 2.3 V	1 kilohm = 23 ma - 23 V
100 ohms = 71 ma - 7.1 V	1 kilohm = 23 ma - 23 V
1 kilohm = 23 ma - 23 V	1 kilohm = 23 ma - 23 V
10 kilohms = 7.1 ma - 71 V	1 kilohm = 23 ma - 23 V
100 kilohms = 2.3 ma - 230 V	1 kilohm = 23 ma - 23 V
1 megohm = .25 ma - 250 V	1 kilohm = 23 ma - 23 V

The decade dials, reading from left to right, have the following values:

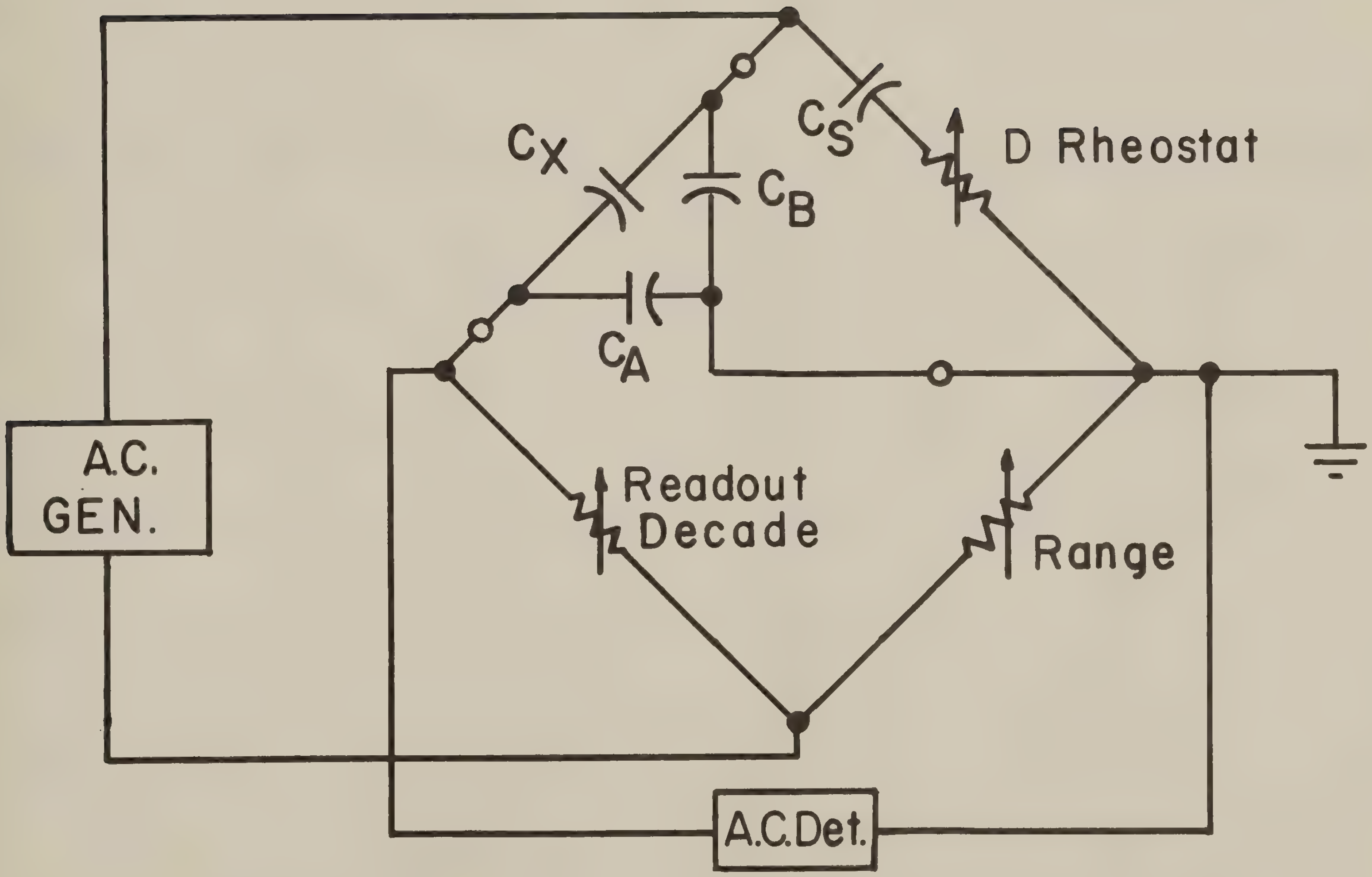
DIAL "A" - 0 thru 11 with 1 kilohm steps.
DIAL "B" - 0 thru 9 with 100 ohm steps.
DIAL "C" - 0 thru 9 with 10 ohm steps.
DIAL "D" 0 thru 105 with 0.1 ohm steps.

The maximum current per step of DIAL "A" is 16 ma.
The maximum current per step of DIAL "B" is 50 ma.
The maximum current per step of DIAL "C" is 160 ma.
The maximum current for DIAL "D" is 250 ma.

NOTE: Refer also to Table 1 and Fig. 5.



Three Terminal Capacitor
Figure 1



Three Terminal Capacitor Connected To Bridge
Figure 2

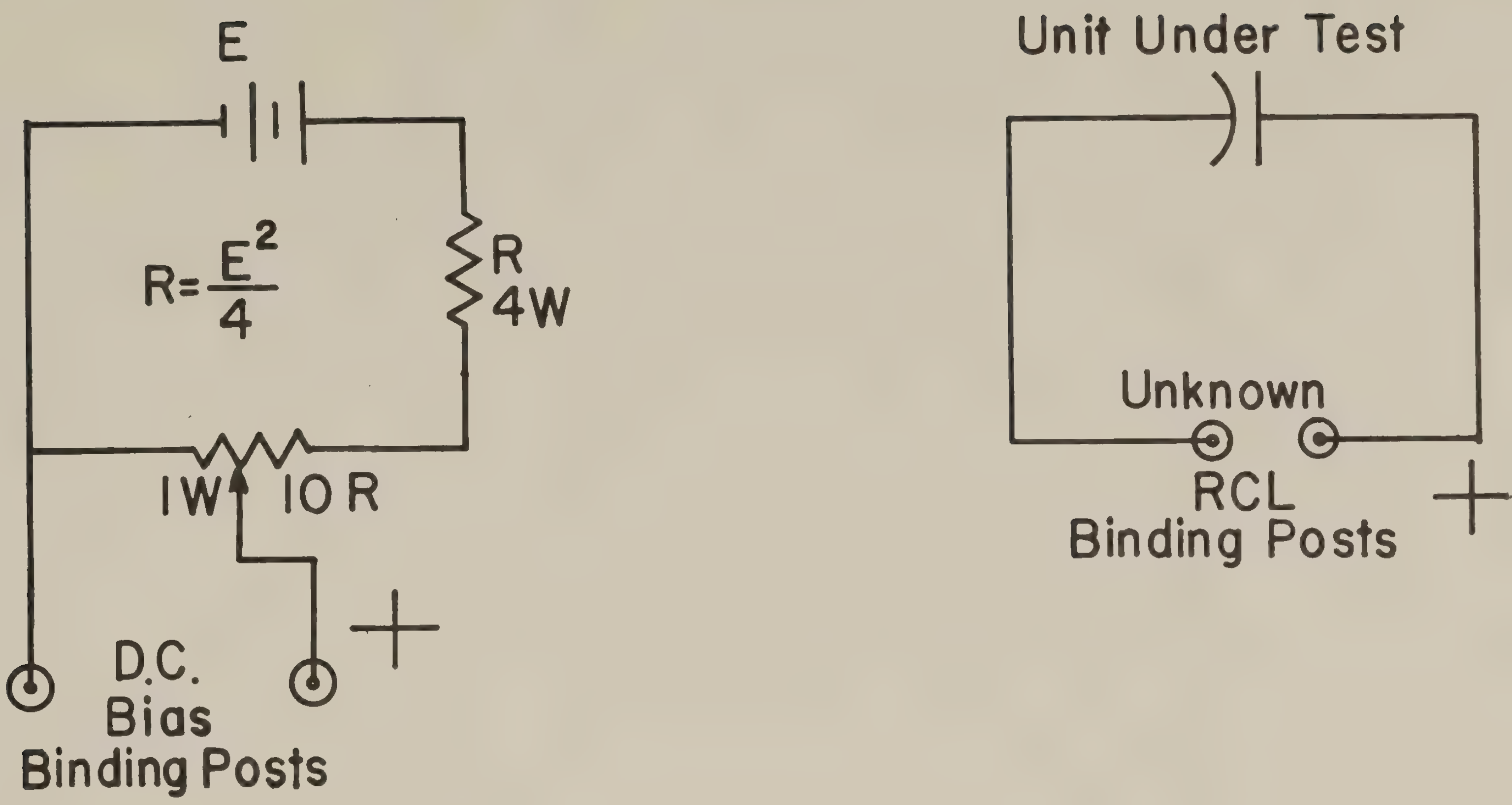


Figure 3

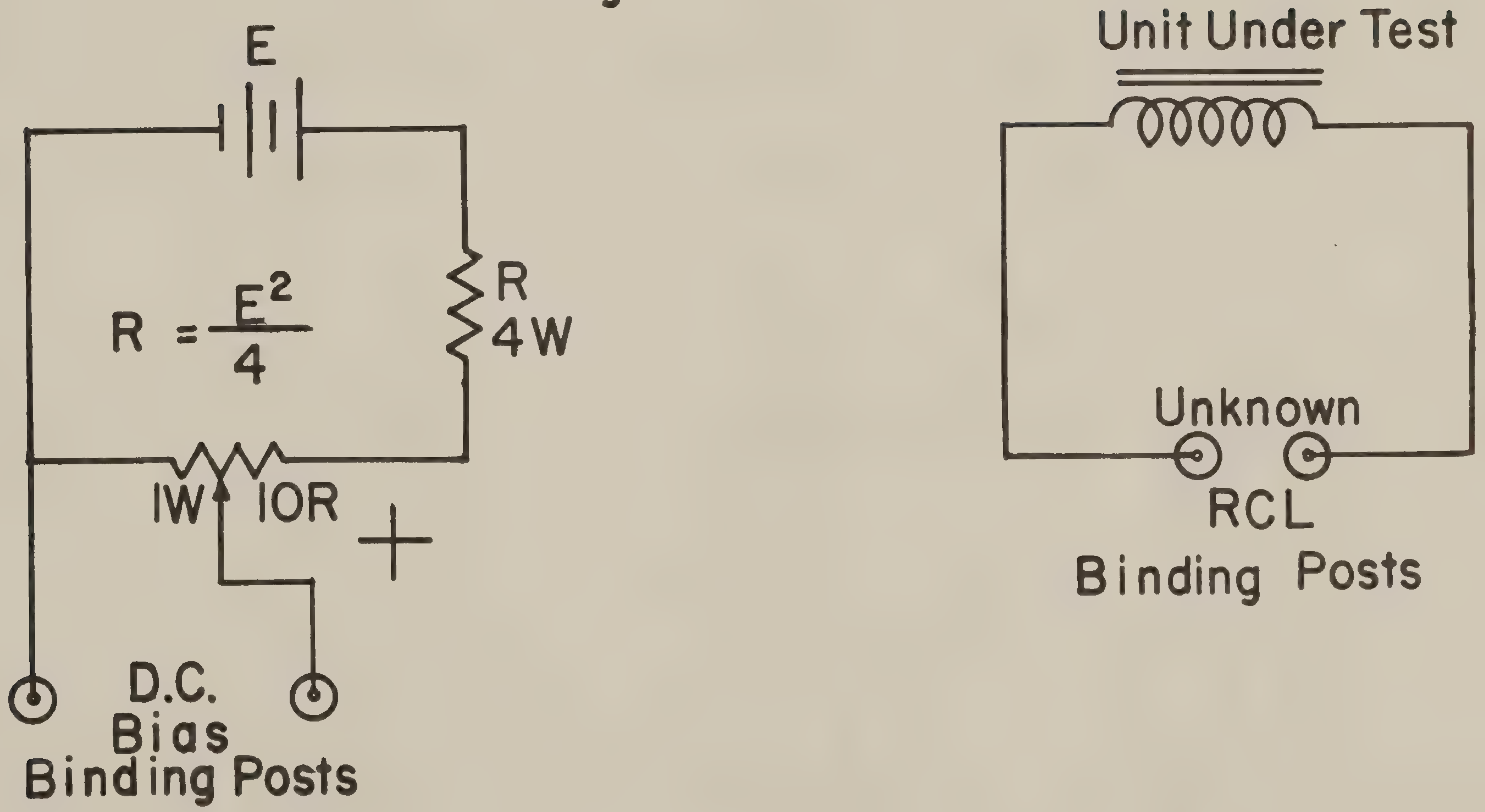
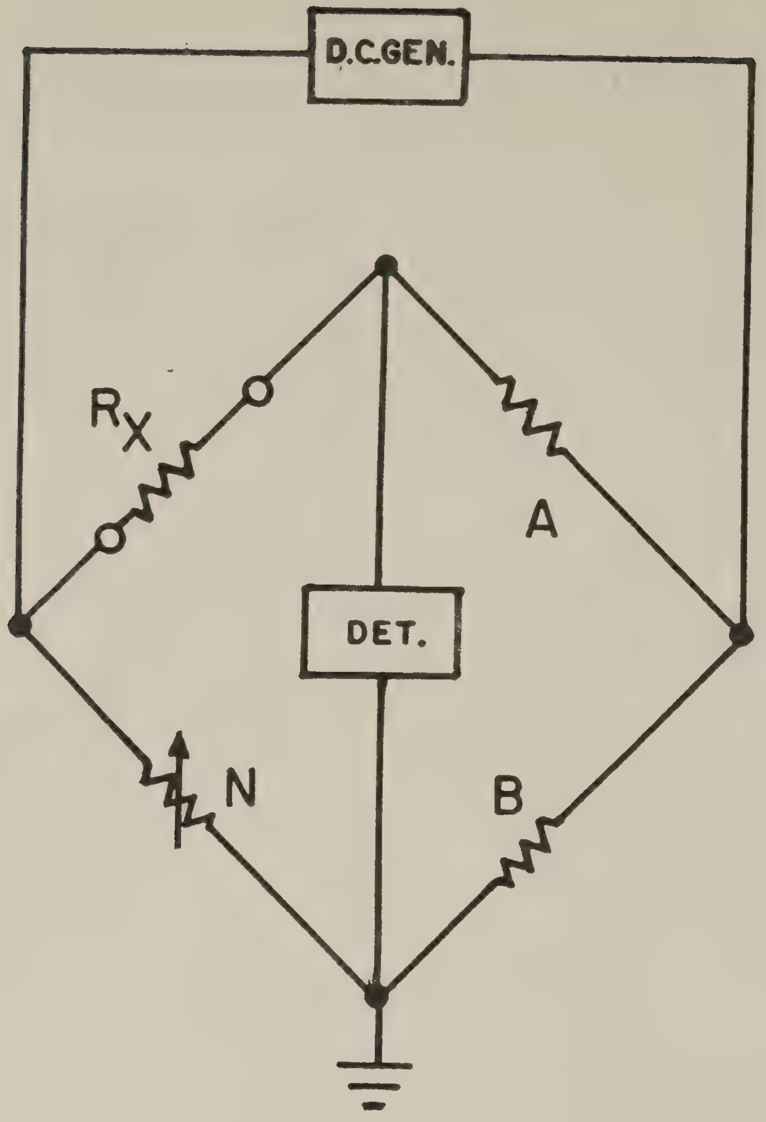
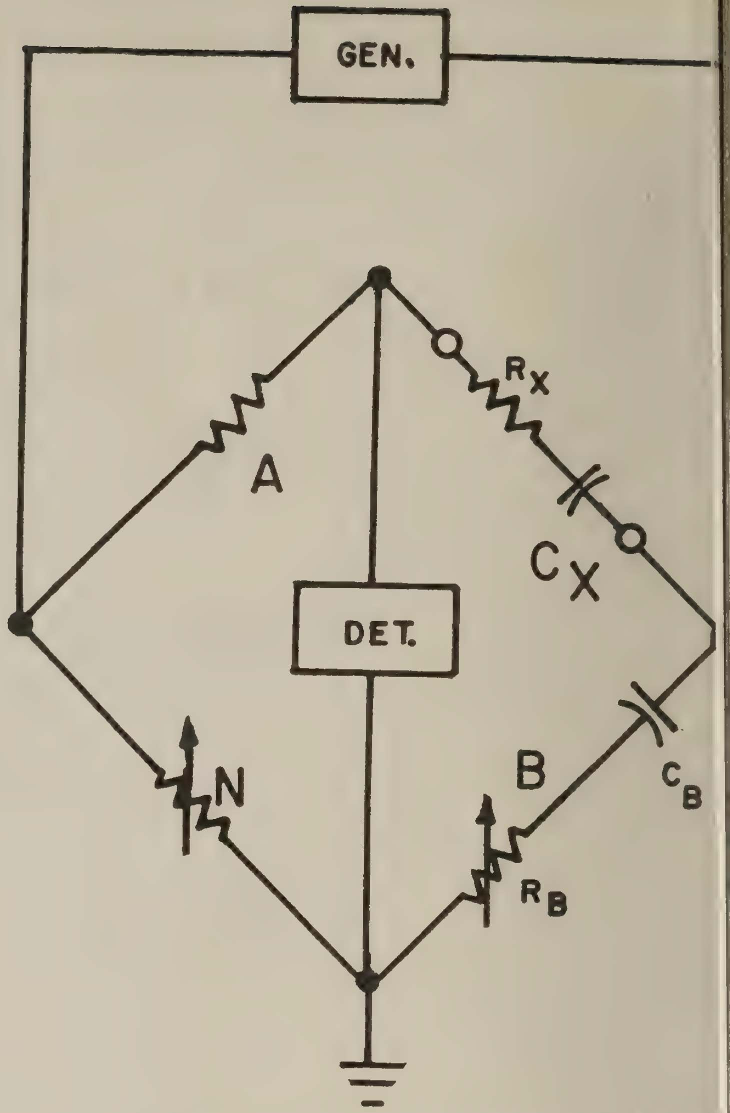


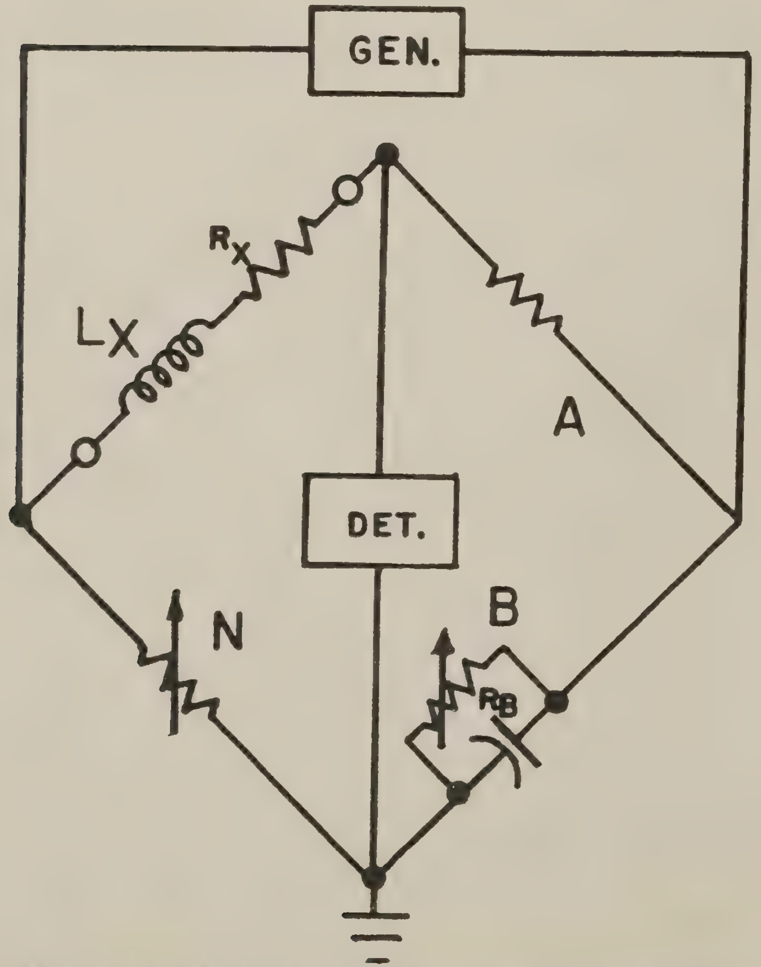
Figure 4



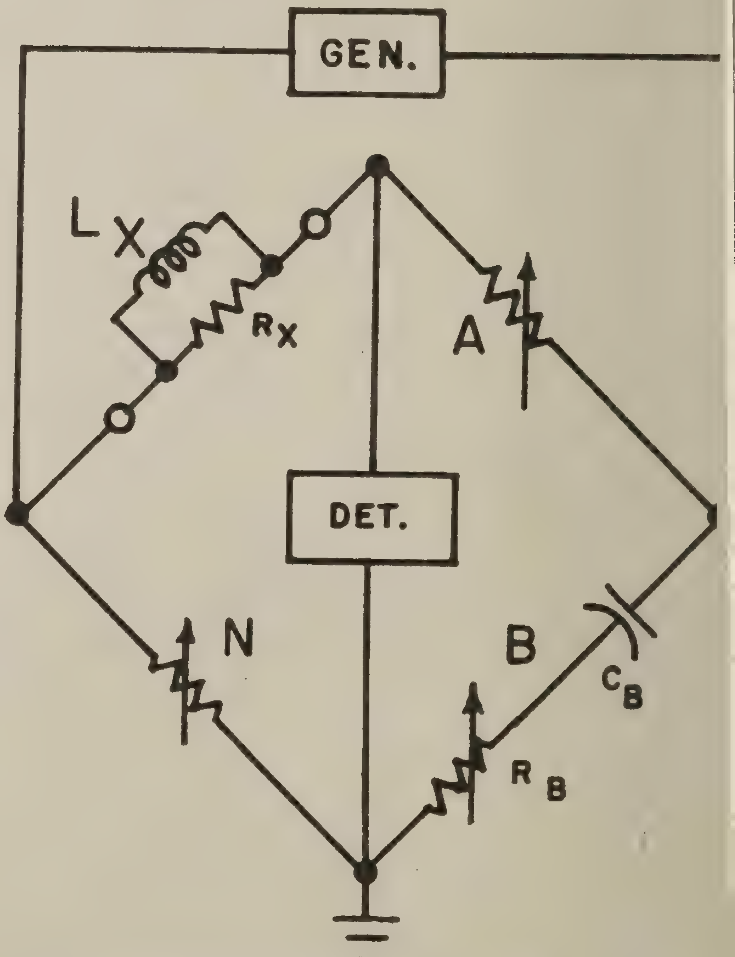
D.C. Resistance Figure 5



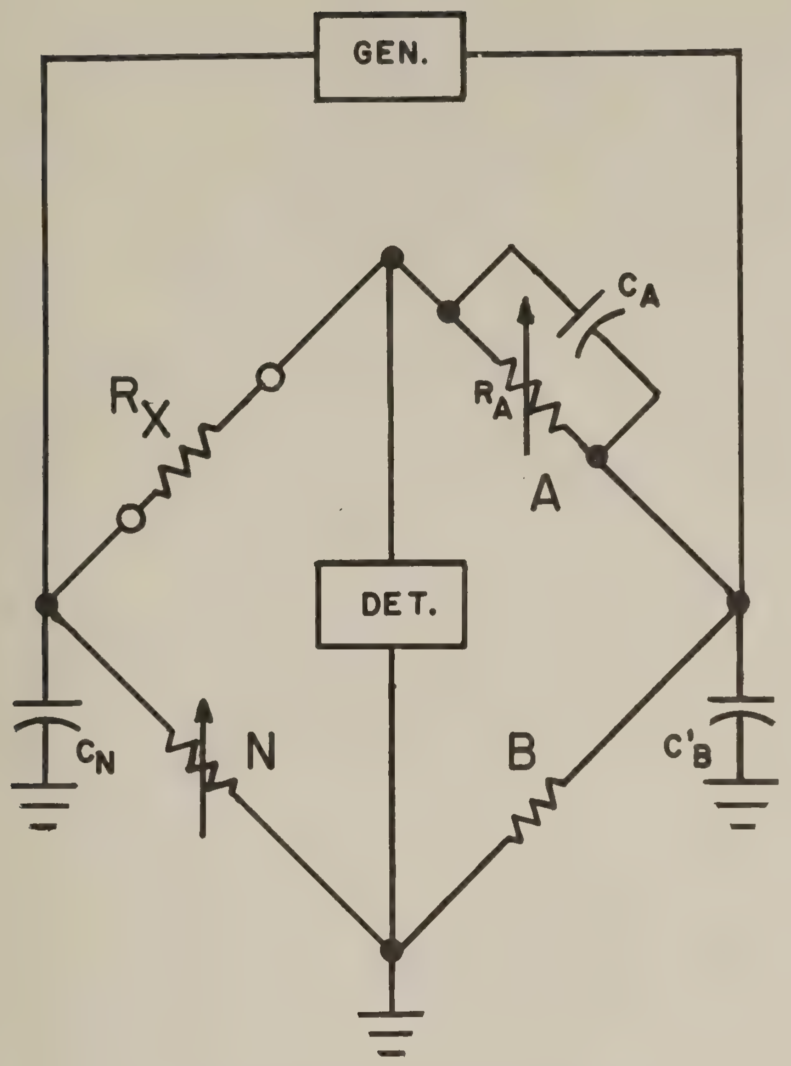
Capacitance Figure 6



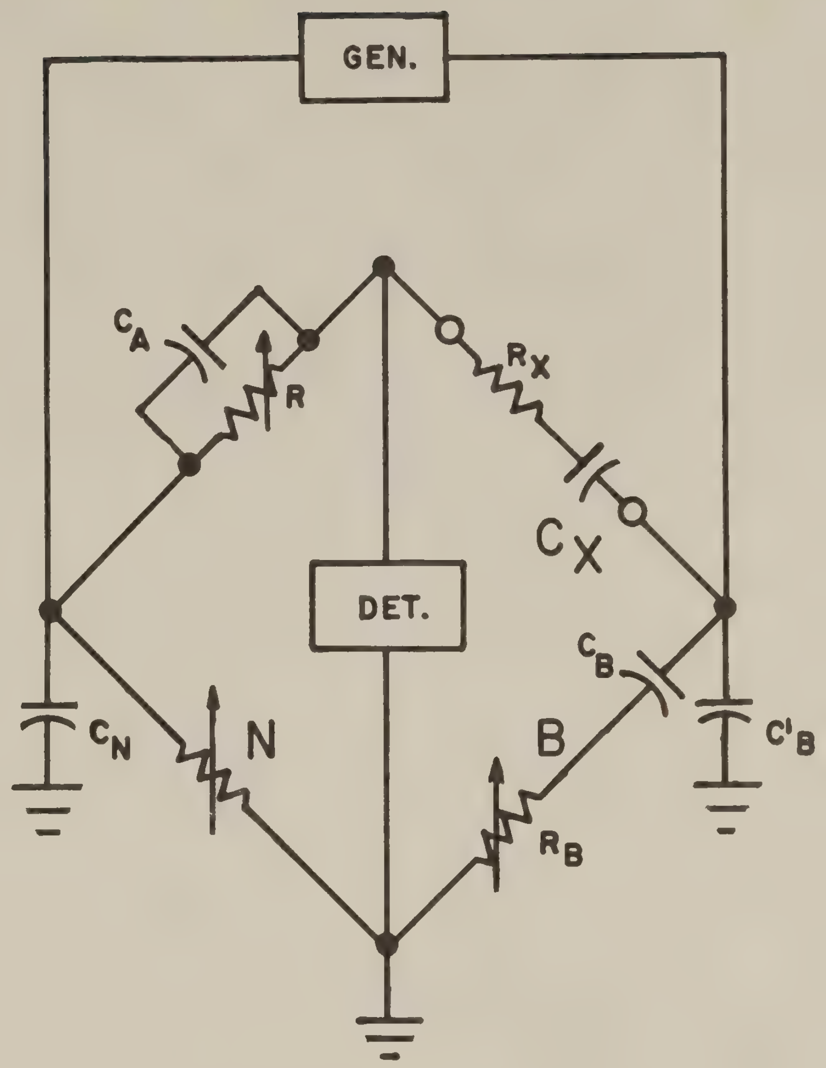
Maxwell Inductance Figure 7



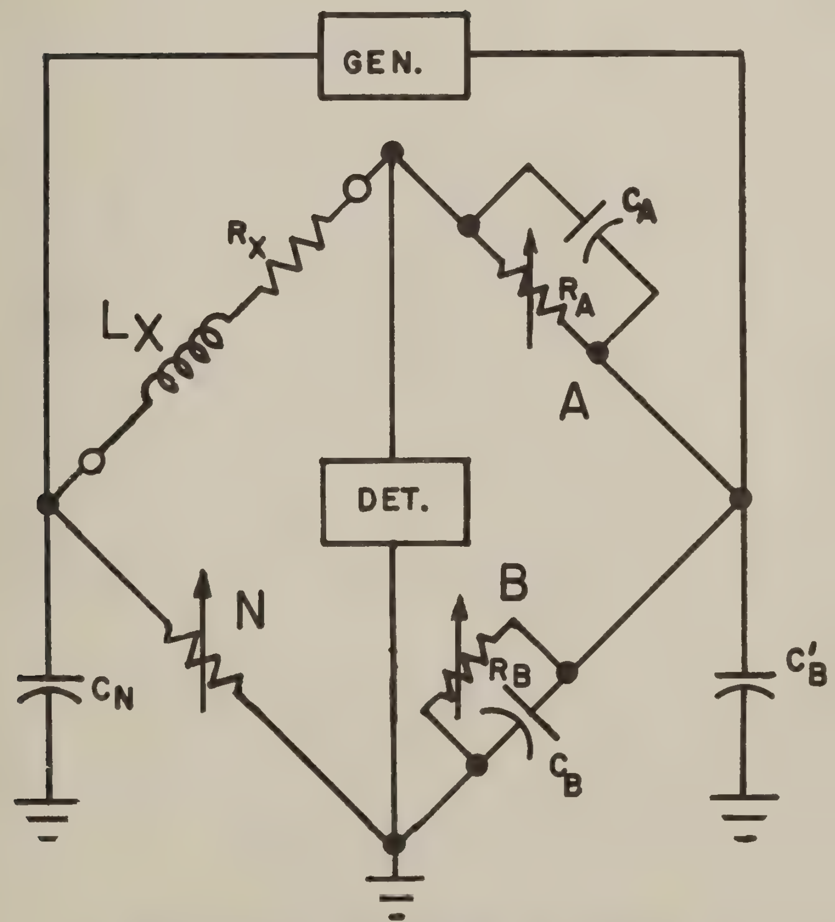
Hay Inductance Figure 8



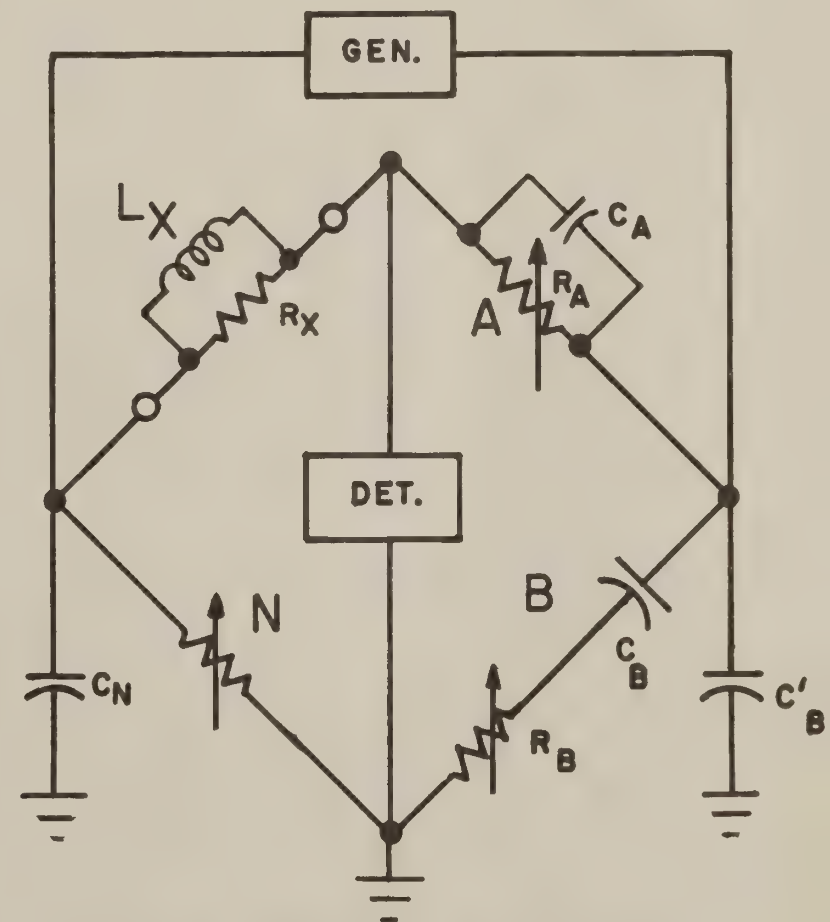
R Bridge Figure 9



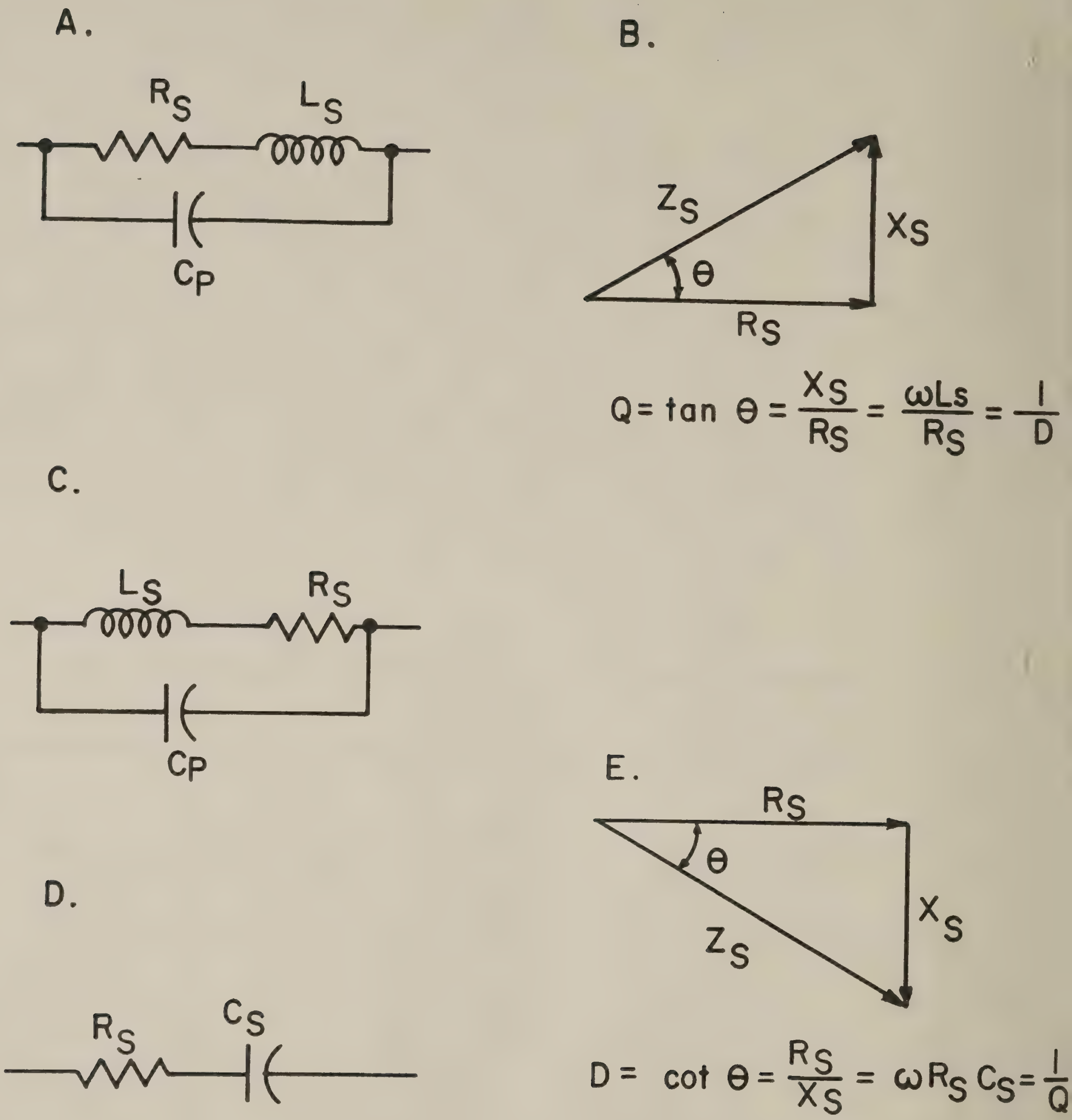
C Bridge Figure 10



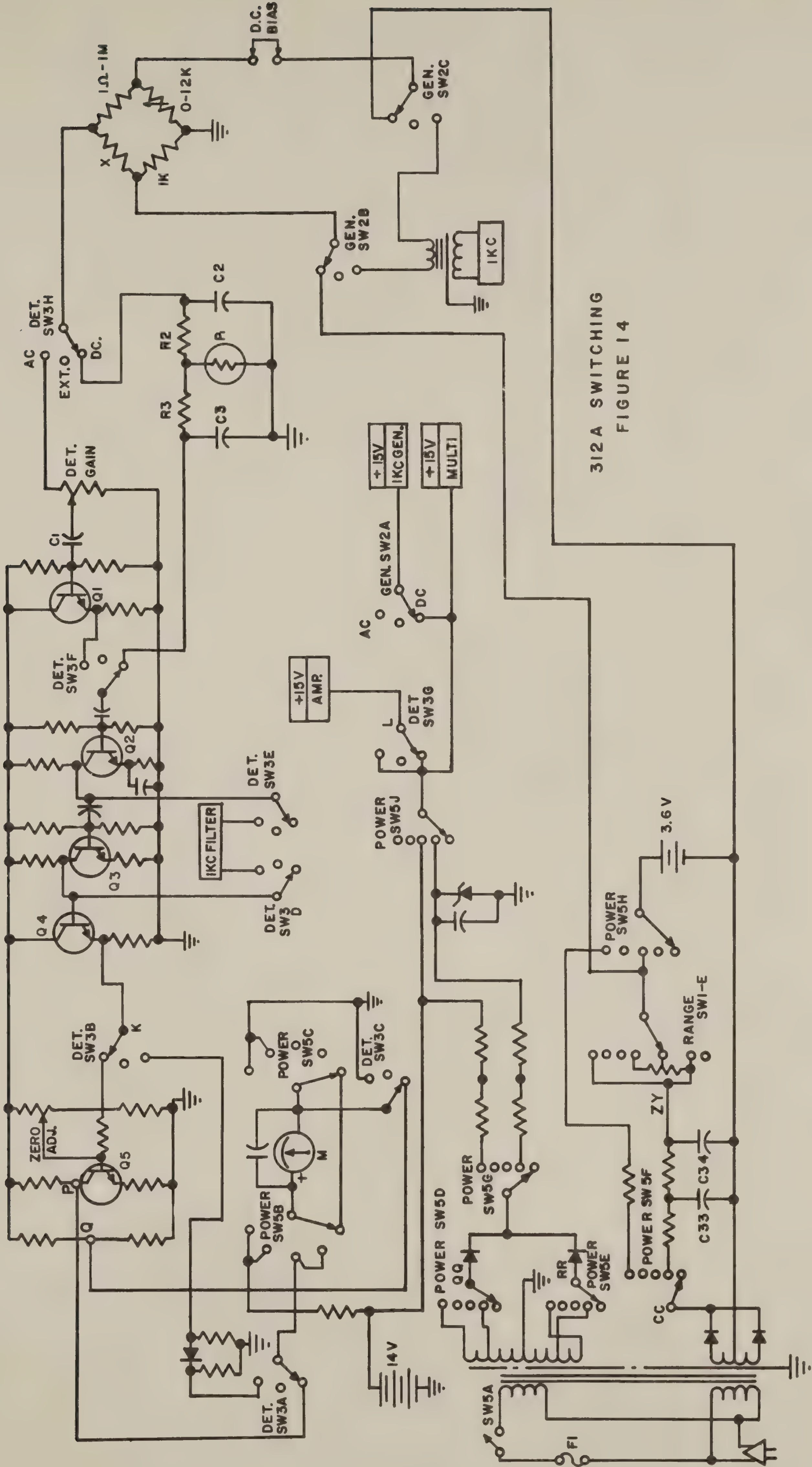
L Maxwell Bridge Figure 11



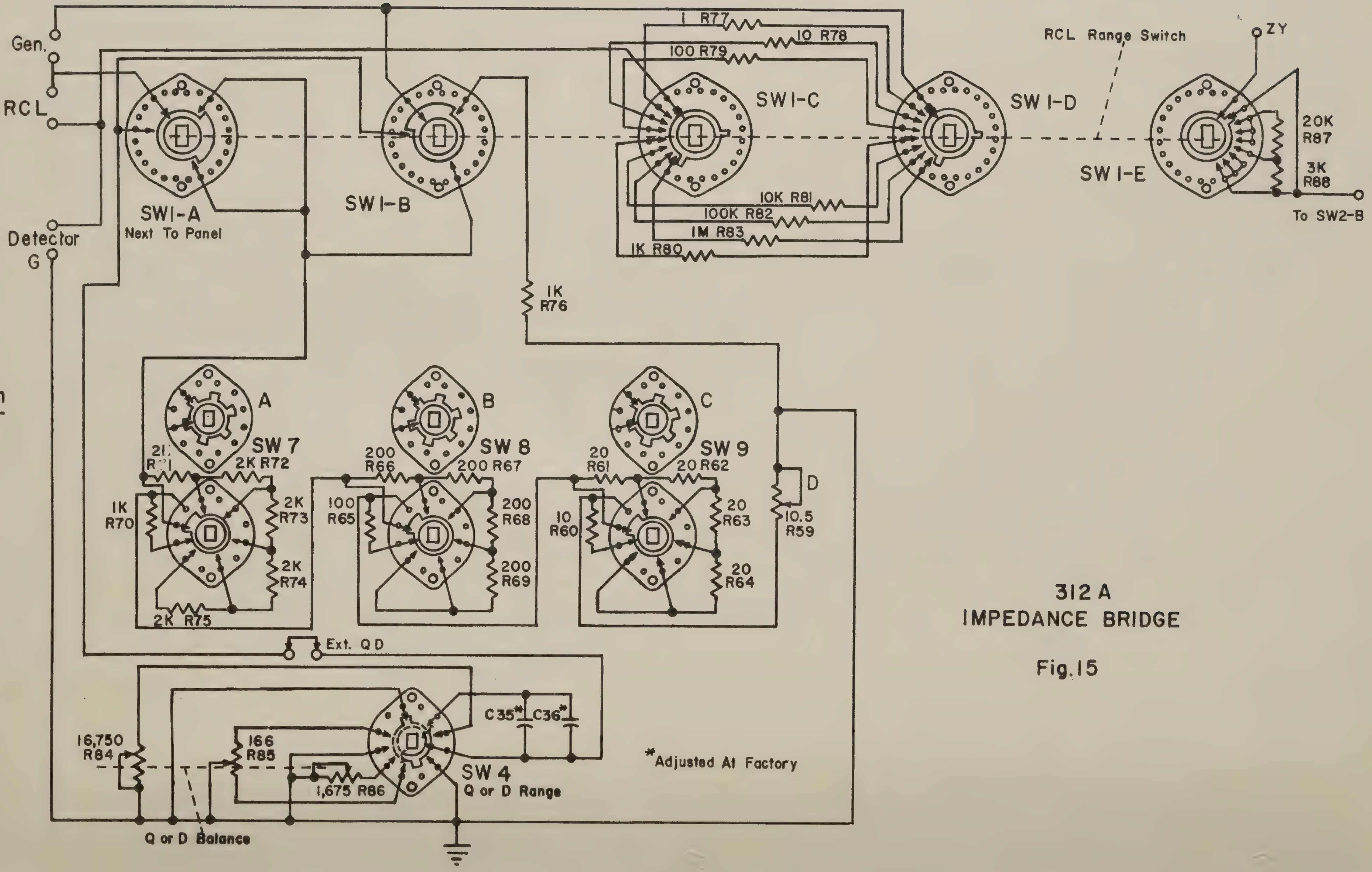
L Hay Bridge Figure 12


A.
R_S
L_S
C_P
B.
Z_S
X_S
θ
R_S
$Q = \tan\theta = \frac{X_S}{R_S} = \frac{\omega L_s}{R_S} = \frac{1}{D}$
C.
L_S
R_S
C_P
D.
R_S
C_S
E.
R_S
θ
X_S
Z_S
$D = \cot\theta = \frac{R_S}{X_S} = \omega R_S C_S = \frac{1}{Q}$

Residual Impedances Figure 13

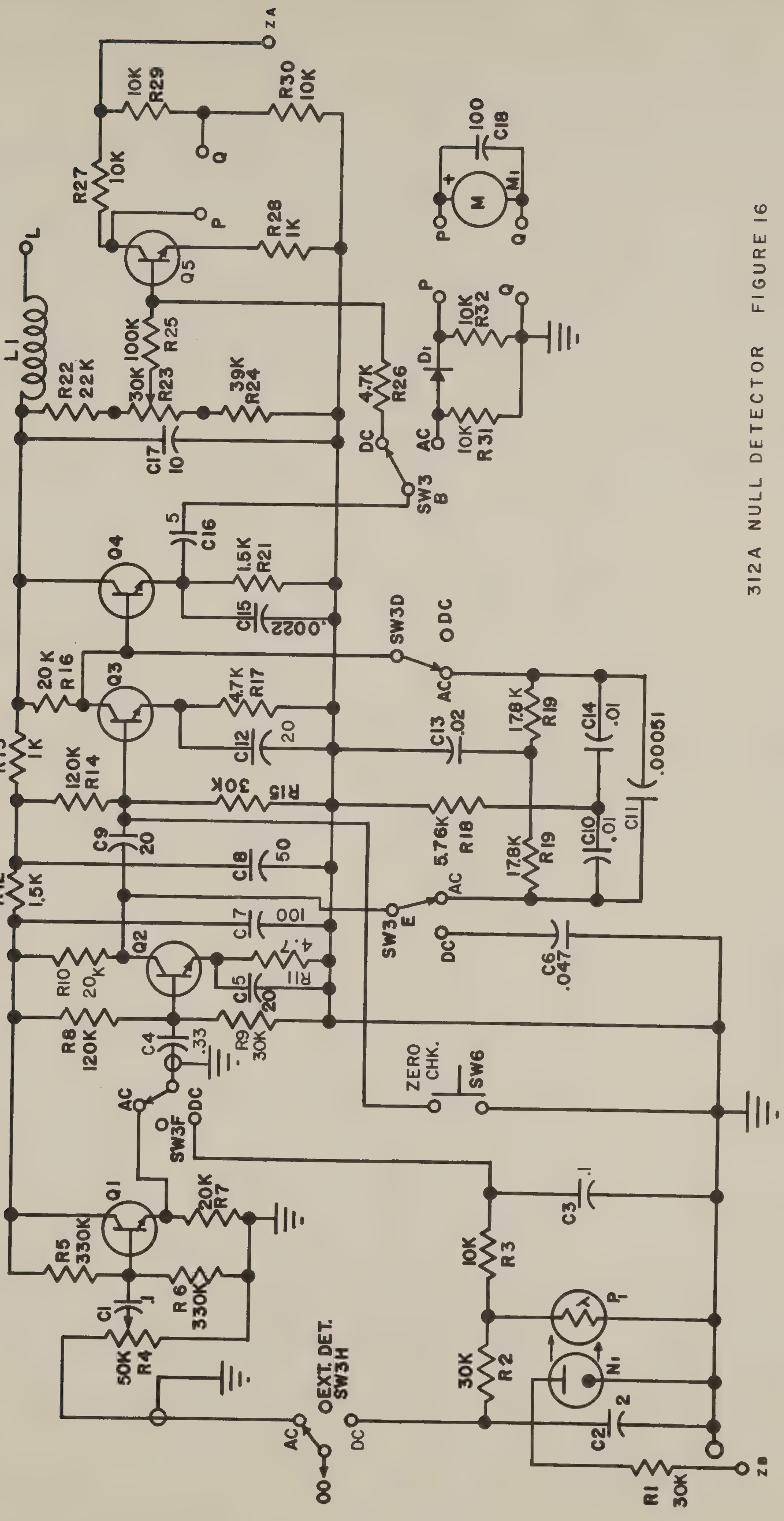


312A SWITCHING
FIGURE 14

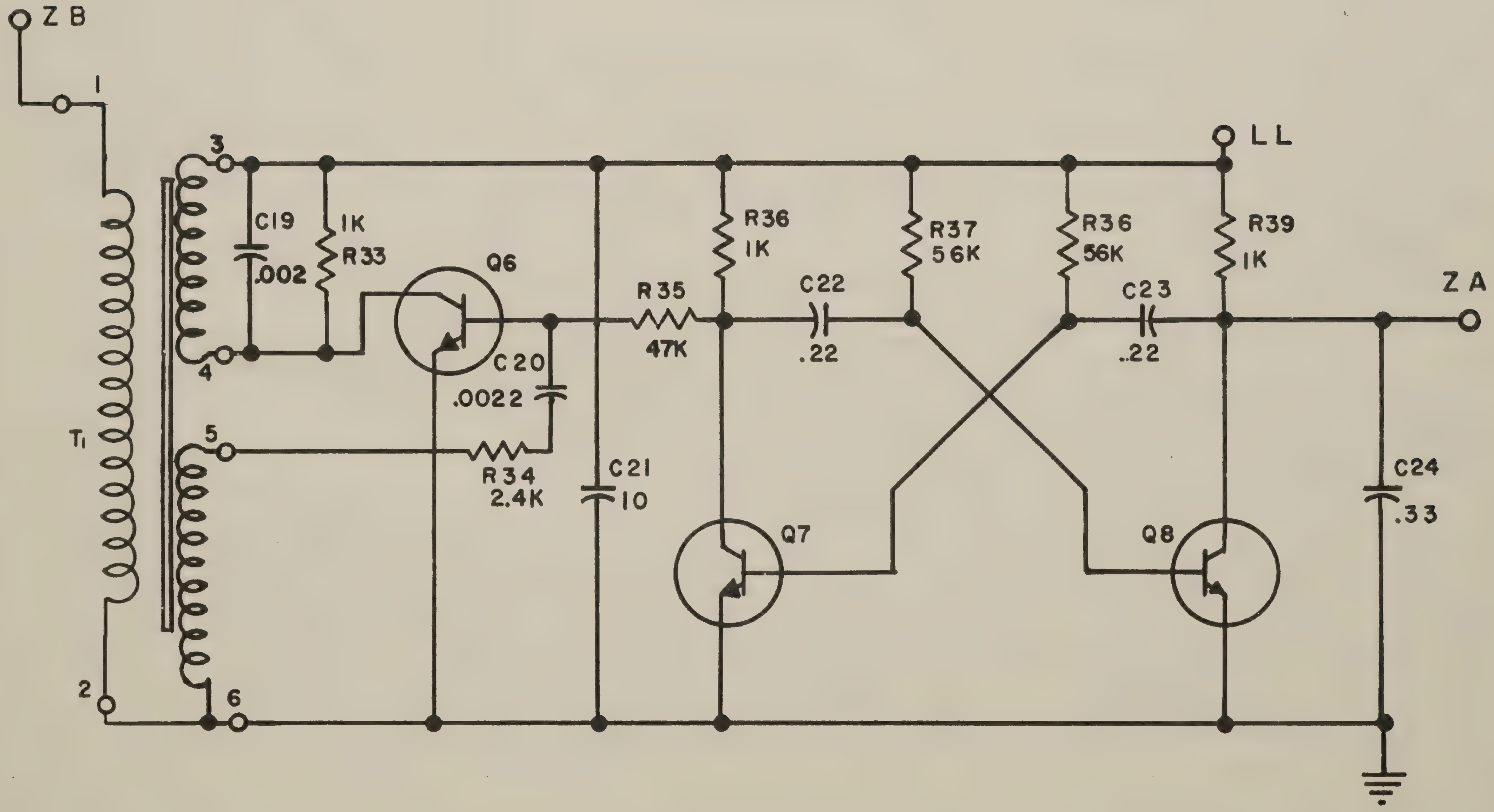


312 A
IMPEDANCE BRIDGE

Fig.15

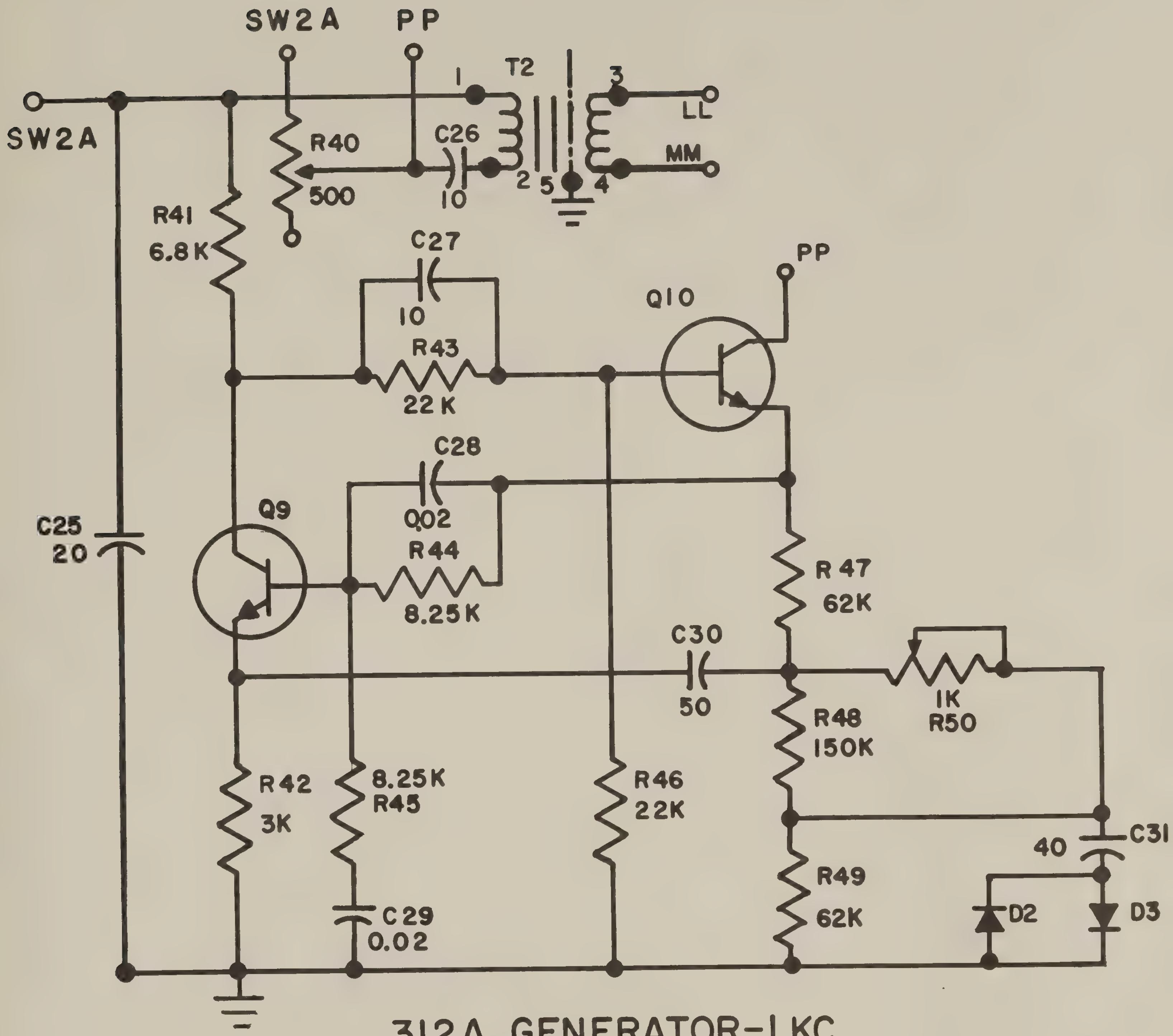


312A NULL DETECTOR FIGURE 16



312A CHOPPER DRIVE

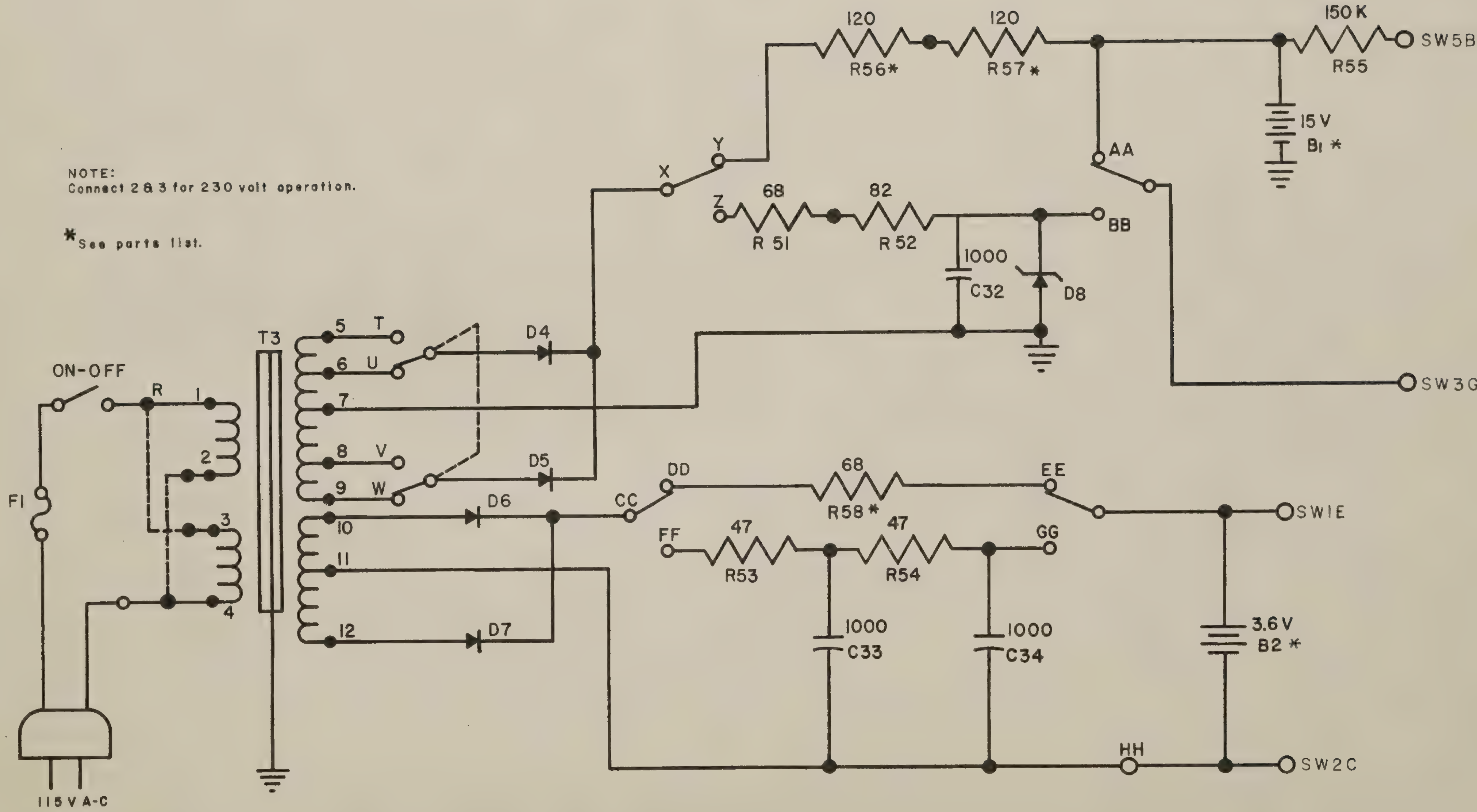
FIGURE 17



312A GENERATOR-1 KC
Fig. 18

NOTE:
Connect 2 & 3 for 230 volt operation.

*See parts list.



312A POWER SUPPLY FIGURE 19

BECO - 312-A IMPEDANCE BRIDGE REPLACEMENT PARTS

Schematic Item No.	BECO Part No.	Description
Capacitor, C7	20-6000	100 mfd. 25V Elect.
Capacitor, C18	20-6001	100 mfd. 12V Elect.
Capacitor, C8	20-6002	50 mfd. 25V Elect.
Capacitors, C17, C26, C27, C21	20-6003	10 mfd. 25V Elect.
Capacitor, C16	20-6004	5 mfd. 25V Elect.
Capacitors, C5, C9, C12	20-6005	20 mfd. 12V Elect.
Capacitor, C30	20-6006	50 mfd. 3V Elect.
Capacitor, C31	20-6007	40 mfd. 6V Elect.
Capacitor, C25	20-6008	20 mfd. 20V Elect.
Capacitors, C32, C33, C34	20-6009	1000 mfd. 25V Elect.
Capacitors, C1, C3	20-9000	0.1 mfd. 100V Mylar
Capacitors, C15, C20	20-9001	0.0022 mfd. 100V Mylar
Capacitors, C4, C24	20-9002	0.33 mfd. 100V Mylar
Capacitor, C19	20-9003	0.022 mfd. 100V Mylar
Capacitors, C22, C23	20-9004	0.22 mfd. 100V Mylar
Capacitor, C6	20-9005	0.047 mfd. 100V Mylar
Capacitor, C2	20-9008	2 mfd. 200V Mylar
*Standard Capacitor, C35-C36	21-1000	0.1 mfd. nom. 0.1% Mica
Capacitors, C10, C13, C13, C14, C29, C29, C28, C28	21-1001	0.01 mfd. 1% Mica
Capacitor, C11	21-1003	510 pF 5% Mica
Choke, L1	22-0000	5.5 mh
Photo Cell, P1	22-1000	CL703CLS, Clairex
Diodes, D2, D3	22-4000	1N91
Diodes, D4, D5, D6, D7	22-4001	1N2069
Diode, D8	22-4002	1N4744A

*Adjusted at factory.

BECO - 312-A IMPEDANCE BRIDGE REPLACEMENT PARTS

Schematic Item No.	BECO Part No.	Description
Diode, D1	22-4003	IN34A
Neon Bulb	23-0000	NE2U
Meter, M1	23-1000	100-0-100 MicroAmp D.C.
Resistor, R4	23-5000	50 K ohm, Gain Adj.
Resistor, R23	23-5001	30 K ohm, Meter Zero Adj.
Resistor, R40	23-5002	500 ohm, Gen. Level
Resistor, R50	23-5003	1 Kc Osc. Waveform Adj.
Q-D Rheostat, R84, R85, R86	23-7000	3-section rheostat
Decade Rheostat, R59	23-7001	10.5 ohm, 1%, W.W.
Resistor, R52	25-0000	82 ohm, 2W, 10% Comp.
Resistors, R53, R54	25-0001	47 ohm, 2W, 10% Comp.
*Resistors, R56, R57	25-0002	120 ohm, 2W, 10% Comp.
Resistor, R51	25-0003	68 ohm, 2W, 10%, Comp.
*Resistor, R58	25-0003	68 ohm, 2W, 10%, Comp.
Resistors, R8, R14	25-0005	120 K ohm, ½W, 5%, Comp.
Resistors, R1, R2, R9, R15	25-0006	30 K ohm, ½W, 5%, Comp.
Resistors, R7, R10, R16, R87	25-0007	20 K ohm, ½W, 5%, Comp.
Resistors, R11, R17, R26	25-0008	4.7 K ohm, ½W, 5%, Comp.
Resistors, R12, R21	25-0009	1.5 K ohm, ½W, 5%, Comp.
Resistors, R13, R28, R33, R36, R39	25-0010	1 K ohm, ½W, 5%, Comp.
Resistor, R24	25-0011	39 K ohm, ½W, 5%, Comp.
Resistor, R34	25-0012	2.4 K ohm, ½W, 5%, Comp.
Resistors, R3, R27, R29, R30, R31, R32	25-0013	10 K ohm, ½W, 5%, Comp.
Resistor, R25	25-0014	100 K ohm, ½W, 5%, Comp.
Resistor, R41	25-0015	6.8 K ohm, ½W, 5%, Comp.

*Supplied only with Battery Pack #312-2

BECO - 312-A IMPEDANCE BRIDGE REPLACEMENT PARTS

Schematic Item No.	BECO Part No.	Description
Resistors, R37, R38	25-0016	56 K ohm, ½W, 5%, Comp.
Resistors, R22, R43, R46	25-0017	22 K ohm, ½W, 5%, Comp.
Resistors, R42, R88	25-0018	3 K ohm, ½W, 5%, Comp.
Resistor, R35	25-0019	47 K ohm, ½W, 5%, Comp.
Resistors, R47, R49	25-0020	62 ohm, ½W, 5%, Comp.
Resistor, R48	25-0021	150 ohm, ½W, 5%, Comp.
Resistor, R6, R5	25-0022	330 K ohm, ½W, 5%, Comp.
Resistor, R55	25-4000	150 K ohm, ½W, 1%, DC
Resistors, R44, R45	25-4001	8.25 K ohm, ½W, 1%, DC
Resistors, R19, R20	25-4002	17.8 K ohm, ½W, 1%, DC
Resistor, R18	25-4003	5.76 K ohm, ½W, 1%, DC
Resistor, R82	25-6000	100 K ohm, 0.025%, MF
Resistor, R83	25-6001	1 M ohm, 0.025%, MF
Transistors, Q1, Q3, Q4, Q5 Q7, Q8, Q9, Q10	27-3000	2N2923
Transistor, Q2	27-3002	2N3391A
Transistor, Q6	27-3001	2N3404
Transformer, T3	28-0000	Power Transformer
Transformer, T2	28-0001	Output Transformer
Transformer, T1	28-0002	Chopper Drive Transf.
Fuse, ½ amp, F1	31-5500	3 AG for 120 V operation
Fuse, ¼ amp, F1	31-5501	3 AG for 230 V operation
Generator switch	32-2800	SW2, A, B, C
Detector switch	32-2801	SW3, A, B, C, D, E, F, G, H
Q-D switch	32-2803	SW4
Power switch	32-2804	SW5, A, B, C, D, E, F, G, H, J
Decade switches	32-2805	SW7, SW8, SW9

ription